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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

EVALUATING THE SUSTAINABILITY OF INFRASTRUCTURE PROJECTS DURING FRONT-END PLANNING PHASE

A thesis submitted in partial fulfillment of

the requirements for the degree of

MASTER OF SCIENCE

in

CONSTRUCTION MANAGEMENT

by

Valentina Ferrer Rivero

2021

To: Dean John L. Volakis
College of Engineering and Computing

This thesis, written by Valentina Ferrer Rivero, and entitled Evaluating the Sustainability of Infrastructure Projects During Front-End Planning Phase, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this thesis and recommend that it be approved.

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Nipesh Pradhananga

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Jose A. Faria

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Mohamed ElZomor, Major Professor

Date of Defense: March 25, 2021

The thesis of Valentina Ferrer Rivero is approved.

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Dean John L. Volakis
College of Engineering and Computing

____
Andrés G. Gil
Vice President for Research and Economic Development
and Dean of the University Graduate School

Florida International University, 2021

DEDICATION

I want to dedicate all my work to my parents and my sisters, for their endless love, support, and encouragement. Without them, I wouldn’t have become the person I am now, and this thesis would have been almost impossible for me.

ABSTRACT OF THE THESIS

EVALUATING THE SUSTAINABILITY OF INFRASTRUCTURE PROJECTS DURING FRONT-END PLANNING PHASE

by

Valentina Ferrer Rivero

Florida International University, 2021

Miami, Florida

Professor Mohamed ElZomor, Major Professor

Front-End Planning (FEP) for Sustainable Infrastructure (SI) projects is a promising process that can support addressing multiple challenges in infrastructure projects (i.e. cost overruns, schedule delays, and poor sustainability). This study aims to investigate synergies between sustainability and FEP tools for infrastructures through stakeholders' surveys, multiple case-study analyses, and a Problem-Based Learning (PBL) activity with students. The PBL activity enhanced students' knowledge on FEP for SI projects, and, together with other analyses, it helped in defining three different frameworks that correlate sustainability and FEP tools for infrastructure projects. The findings of this thesis contribute to the infrastructure, engineering and construction education bodies of knowledge through (1) paving the way for the future workforce to understand the criticality of infrastructure sustainability and the importance of the FEP process in these projects; and (2) supporting stakeholders in better planning, assessing risks and managing sustainable infrastructure projects prior to project initiation.

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CHAPTER I

I.1. Synthesis of the study

Sustainable Infrastructure plays a critical role to improve the quality of life for the public, cultivate resilience against extreme weather and recurring disaster events as well as ensure sound economic development. However, to this end, many infrastructure projects fail to meet their sustainability goals and are often plagued with schedule delays and cost overruns. Two effective techniques that support addressing these challenges are the Front-End Planning (FEP) process and the Envision™ rating system which in combination can potentially help manage complex infrastructure projects and embrace their sustainability. This study aims to investigate synergies between Envision™ and the FEP tools called the Project Definition Rating Index (PDRI), through the determination of correlations between 43 scope definition elements and 59 sustainability credits from Envision™. To achieve this objective, this research surveyed 109 stakeholders of more than 45 Envision™ projects, which represents around 60% of the current Envision certified projects in the U.S. Additionally, the study integrated a Problem-Based Learning (PBL) activity within a construction management (CM) class to enhance students' knowledge on FEP and sustainability criteria for infrastructure projects. Then, a pre-and post-survey of 45 CM students recorded the gain in students' knowledge and skills. A paired t-test analysis of the data indicated that even with the scarce understanding of FEP techniques, students comprehended the importance of synergy between sustainability practices and FEP on an infrastructure project. Similarly, based on an ordered probit regression analysis of the data obtained in the 109 stakeholders' survey, the respondent's awareness of sustainability procedures, a projects' value, financial performance, and change management performance have a positive correlation with the expected success of a sustainable infrastructure project indicating that with the increase in the value of these factors, the rate of success of a sustainable infrastructure project is more likely to increase. Additionally, the stakeholders' responses and a multiple case-study analysis helped in the development of three different frameworks: (1) an Envision™ and Basis of Design matrix, (2) an Envision™ and Basis of Project Decision matrix, (3) and the Sustainability and FEP matrix developed from the stakeholders' perspective. The findings of this thesis contribute to the infrastructure, engineering and construction education bodies of knowledge through (1) encouraging STEM educator to prepare future engineering workforce with required knowledge and skills in the Envision-FEP framework; and (2) supporting construction stakeholders to integrate sustainability and resilience in infrastructure projects prior to project initiation, reduce project risks as well as develop the project scope, planning, funding alignment, and objectives efficiently.

I.2. Introduction

Sustainability is an important worldwide concern; addressing climate change and global warming is becoming an emerging necessity in the construction industry, which introduces a new challenge not only in the design of projects but also in the construction and operation phases. Low awareness of a project's societal and environmental impacts and a lack of standardized procedures to quantify these impacts are often roadblocks to achieving sustainability (Weerasinghe et al. 2007). Infrastructure projects may be responsible for multiple challenges, including planning complications, more underground works, more impacts on the public and the environment, and larger investments than other types of construction projects. Despite the vital mission and significance of civil infrastructures, such projects are often plagued with schedule delays, cost overruns, and failure to meet their sustainability goals. Thus, there is an existing need for infrastructure projects with improved project performance and low environmental and social impacts.

Incorporating traditional planning is vital to address the additional efforts during the planning, design, construction, and operation phases of sustainable projects, yet Front-End Planning (FEP) remains paramount. FEP comprises all the tasks between project commencement and the initiation of the detailed design (Weerasinghe et al. 2007). Nowadays, construction companies need to shift from focusing on the cost, time, and quality performance of a project, to also include the Triple Bottom Line (TBL) impacts by incorporating sustainability into project management (Silvius and Schipper 2014). To this end, coupling FEP tools [i.e. the Project Definition Rating Index (PDRI)] and sustainability practices may be a versatile solution. In fact, existing sustainable rating systems (i.e. LEED and Envision™) work as a framework that help ensure that the "right" project is planned, designed, and delivered in a sustainable and resilient manner (ISI 2018; Weerasinghe et al. 2007).

Sustainable development mitigates environmental damage while supporting human dignity. It offers alternatives in dealing with environmental issues and meeting people's expectations in terms of comfort and quality (Weerasinghe et al. 2007). Sustainable design aims to improve the built environment's performance through a suite of economic, social, and environmental aspects, or as it is usually called: "The Triple Bottom Line (TBL)" (Elkington 1998). Choguill (1996) highlighted that urban sustainability is unattainable without the development of an adequate infrastructural foundation in urban areas.

Sustainable physical infrastructure developments are considered critical factors for steady economic growth since they are responsible for conveying people and freight (Canning 1998). It is known that most of the natural resources are finite and community development has consequences that affect the TBL, thus the construction of infrastructures should not only be robust, but it must also be sustainable (ISI 2015). The construction industry has spotlighted green buildings as an approach to creating a more sustainable built environment. However, infrastructure projects have typically been left out of sustainable construction efforts, which may be because of the many challenges that stakeholders must encounter resulting in increased difficulty assessing sustainability. Thus, this research aims to help infrastructure stakeholders better assess the sustainability of their projects by demonstrating how FEP, jointly with sustainable design, can maximize the possibilities of a successful project.

I.3. Research Objectives, Questions, and Hypotheses:

This research targets four main objectives: (1) assess the pedagogical needs to integrate Envision-PDRI framework for preparing future construction workforce; (2) analyze the correlation between each element on the Envision™ Rating System and the PDRI tools for infrastructure projects; (3) validate the correlation through case study surveys; and (4) develop conceptual frameworks and statistical models for interpreting the collected data.

This research includes five questions: (1) what are the strengths and weaknesses of the implemented Problem-Based Learning (PBL) activity in terms of improving students' knowledge and ability to work with FEP and SI tools?, (2) what are the students' perception on the convenience of coupling FEP and sustainability for infrastructure projects?, (3) what is the student's level of interest in including FEP for infrastructure projects and SI in the STEM curricula?, (4) what are the different factors that influence the convenience of coupling FEP and Envision for infrastructure projects?, and (5) what are the existing synergies between sustainability for infrastructure projects and the FEP process?

The study also tested three research hypotheses formulated for statistical analysis which includes:

Hypothesis #1 The adoption of sustainability criteria and PDRI elements enhances the performance of an infrastructure project, in terms of cost, schedule, change orders, and resiliency.

Hypothesis #2 The integration of the Envision-PDRI framework in the early stages of a project ensures the success of infrastructure projects.

Hypothesis #3 FEP and SI concepts provide undergraduate and graduate Construction Management (CM) students an edge in their professional careers.

I.4. Background and Motivation

I.4.1. Infrastructure projects

Infrastructure projects play a critical role in the built environment; they provide the basis for personal security and public health, influence the economic growth and competitiveness of communities, provide drinking water and handle waste, and, most importantly, allow building and industrial projects to connect with all main utilities. In comparison to building projects (vertical construction), infrastructure projects are “horizontal” and act as vectors that connect residential and industrial nodes as well as provide services and goods within the built environment. Thus, due to such nature of infrastructure systems, these are commonly overlooked and underfunded until the service is interrupted or deteriorated. According to ISI (2018a), massive investments in infrastructure are now needed due to decades of negligence and outdated infrastructure around the world. The American Society of Civil Engineers (ASCE) rates the U.S. infrastructure every 4 years; a group of civil engineers assesses all relevant data and reports from the US infrastructure system following a set of criteria that includes the capacity, the condition, the funding, the operation and maintenance, the resilience and more. The ASCE 2021 report card stated that the US infrastructure system achieved a score of C-. This indicates a mediocre system that requires attention (ASCE 2021) and confirms that the system is deteriorating due to negligence, overuse, poor investment, and inappropriate construction practices (ASCE 2017; Canning 1998). Furthermore, proper planning for infrastructure projects, or better-called infrastructure management (IM), is often not met due to the complexity of such projects, thus causing schedule overruns and failure to meet the forecasted budgets. Research shows that, despite the usual practices, the best way to deliver a project is focusing on the Front-End Planning (FEP) phase, prior to authorizing its funding and subsequent construction (Cho and Gibson, Jr. 2000; CII 2013). The FEP of a project is a fundamental process of scope definition so that the stakeholders can address and minimize risks to accomplish improved project outcomes (Hamilton and Gibson 1996). Applying FEP practices to infrastructure projects is vital for the development of these projects, and thus, maintain access to critical goods and services throughout the nation.

Infrastructure projects require large investments and result in high impacts on the built environment as well as the served communities. Thus, these kinds of projects pose many environmental and social repercussions over the sustainability of the built environment. Since most of the natural resources are finite and community development has consequences that affect the TBL, the construction of infrastructures should not only be cost-effective, but it must also be sustainable (ISI 2015). The concept of sustainability originated in the late 1980s after the United Nations' Brundtland Commission Report identified it as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Keeble 1988). Nowadays, sustainability concepts have become more vital among the architecture, engineering, and construction (AEC) industries.

Sustainable infrastructure (SI) and infrastructure management (IM) are typically seen as two different and distinct topics, and yet these are strongly related. Coupling FEP and sustainability practices can significantly increase project performance. In fact, existing sustainable rating systems [i.e. Leadership in Energy and Environmental Design (LEED) and Envision™] work as a framework that helps ensure that the "right" project is planned, designed, and delivered in a sustainable and resilient manner. These rating systems provide a standardized pre-project planning process that takes into account the TBL (ISI 2018; Weerasinghe et al. 2007). Previous research confirms that FEP tools, such as the Project Definition Rating Index (PDRI), combined with sustainable rating systems (LEED) provide a comprehensive framework for FEP of sustainable building projects. Additionally, it has been indicated that a sustainable building project would usually emphasize more on thorough FEP than conventional projects, resulting in better cost performance and reduced change orders (Weerasinghe et al. 2007), (Kang et al. 2013). To this end, FEP and sustainability tools for infrastructure projects are briefly presented in the following sections.

I.4.2. Front-End Planning and PDRI

Front-end planning (FEP) is a critical process that establishes a suitable scope definition and a structured approach for a project while uncovering any project unknowns and risks (Bingham and Gibson 2017). Previous research has demonstrated the significance of FEP tools on capital projects and how they correlate with a project's success (Gibson et al. 2006; Sherif and Price 1999). Hansen et al. (2018) compiled 30 years of valuable FEP literature review in response to the low general understanding of FEP and how it differs from traditional project planning. Their research included the strong need for implementation of FEP, a concise differentiation between FEP and traditional planning, the benefits and challenges of implementing FEP, and more. The CII (2006) indicated that despite the requirement for initial investment for FEP even higher savings can be achieved on a project. Typically, FEP costs around 2.5% of total project cost but will return on average 10% cost savings, 5% fewer changes, and 7% shorter schedule delivery. According to Bingham and Gibson (2017), the FEP process in infrastructure projects can contribute to identifying and mitigating risks stemming from issues such as environmental hazards, permits, right-of-way concerns, utility adjustments, and logistic problems. CII (2006) also highlighted that proper FEP can help achieve project objectives such as improved scheduling, cost, and operating characteristics, as well as social and environmental goals.

Poor scope definition in a project may adversely affect the project's schedule, cost, and operational performances. Thus, one of the major tasks in FEP is developing proper and sufficient strategic information to create a strong link between the project goals and scope throughout the entire project's life cycle (Gibson et al. 2010). Despite the importance of correctly defining the scope of a project, many owners and contractors neglect the criticality of FEP and thus are plagued by poor project performance that leads to a deficient design basis (Cho and Gibson Jr. 2001). As an effort to overcome such challenges, the Project Definition Rating Index (PDRI) tools have been developed. PDRI is a weighted matrix with scope definition elements that allows stakeholders to assess, quantify, and rate the level of scope definition and readiness for project execution, before detailed design and construction (CII 1997, 2001, 2006). The Construction Industry Institute (CII), together with Cho and Gibson, Jr. (2000), Bingham and Gibson Jr. (2010), Elzomor and Parrish (2017), Collins et al. (2017) among others, created the different PDRI tools: PDRI-General Buildings Projects, PDRI-Infrastructure Projects, PDRI-Small Infrastructure Projects, and PDRI-Small Industrial Projects, respectively. This thesis focuses on the PDRIs for infrastructure projects only.

The PDRI tools include a structured list of scope definition elements categorized in three separate sections: Section I. Basis of Project Decision, Section II. Basis of Design and Section III. Execution Approach. Then, these sections are broken down into subcategories with their respective elements, as shown in

Figure 1. All PDRI sections, categories, and elements can be found in Appendices A and B. PDRI – Small Infrastructure consists of 40 scope definition elements grouped

into 8 categories, while PDRI-Infrastructure (Large infrastructure projects) entails 68 elements grouped into 16 categories. Both tools have a maximum score of 1000 points, where a lower score indicates a project with a greater level of scope definition, and a higher score indicates a lesser amount of scope definition (Elzomor et al. 2017). In other words, projects with lower PDRI scores usually maintain more robust cost and schedule performance than those with higher PDRI scores.

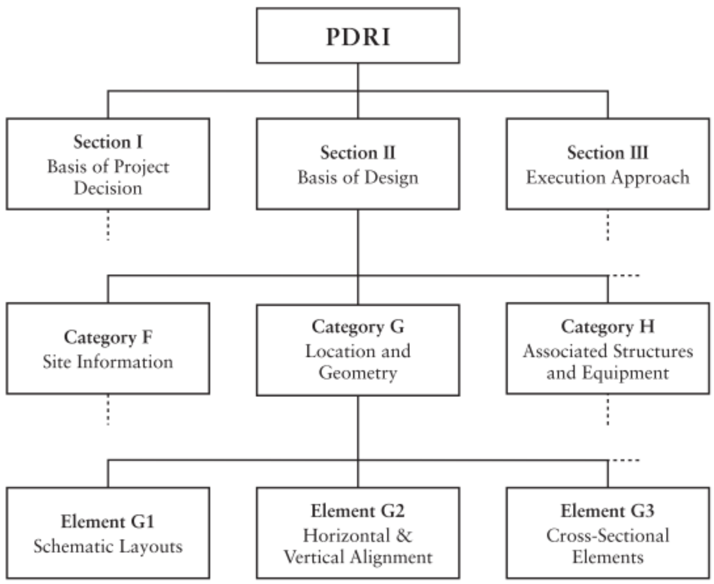

Figure 1. PDRI-Infrastructure Partial Hierarchy. (Source: CII 2013)

Although all PDRI tools are divided into the same three categories, each tool has its unique complexities to score each of the respective categories. The first category, Basis of Project Decision, consists of information necessary for understanding the project objectives, which indicates whether the project team is strongly aligned to fulfill the project's business objectives and drivers. Similarly, the second category, Basis of Design, highlights processes and technical information elements that should be evaluated for a full understanding of the engineering/design requirements necessary for the project. Lastly, the third category, Execution Approach, consists of elements that should be evaluated for a full understanding of the owner's strategy and required approach for executing the project construction and closeout (Elzomor et al. 2017). Elzomor et al. (2018) carried out a comparative study between PDRI for small infrastructure and PDRI for large infrastructure in terms of their structure, content, weight, and target score of the elements. The authors determined that the most important section for PDRI-Small Infrastructure was Section II: Basis of Design, with 470 points, while for PDRI-Infrastructure the highest weighted section was Section I: Basis of Project Decision, with 437 points. This is related to the fact that large infrastructure projects frequently need a more robust decision-making effort to define the project scope, while small infrastructure projects may be less complex and already have the location and scope defined prior to the FEP phase.

Cho and Gibson Jr. (2001), summarized FEP in five major processes: (1) initiation, (2) scope planning, (3) scope definition, (4) scope verification, and (5) scope change control. Gibson and Gebken (2003) recommended the implementation of PDRI in all five steps of FEP. During the initiation, the PDRI tool serves as guidance in defining the project strategy and objectives. In scope planning and scope definition phases, the PDRI helps in defining a scope management plan and assigning roles to each stakeholder. For the scope verification process, the PDRI specifies the quality and level of completeness of the project, and aids in the decision-making process of moving forward to the construction phase. Finally, in the scope change control, the PDRI shows which elements have been poorly defined and need attention, which allows the project team to act and improve those deficiencies.

PDRI is an important tool for its efficient use during FEP in terms of evaluating how likely a project is to achieve a specific set of objectives, including social and environmental considerations (Kang et al. 2013). Kivilä et al. (2017) stated the significance of integrating sustainability criteria during the entire project management process, particularly in large infrastructure projects that have long-lasting effects on society.

Despite all advantages that the PDRI can grant to a project, only a few research studies have connected it to sustainability purposes. PDRI tools are rarely applied to sustainable projects because of a lack of understanding about sustainability and the perception of possible higher costs than conventional construction (Hansen et al. 2018). One research study that did connect PDRI with sustainability showed a positive relationship between this FEP tool and the cost performance of sustainable building projects, even stronger than the one existing in conventional buildings (Kang et al. 2013). Similarly, Weerasinghe et al. (2007) investigated the use of the LEED building rating system in FEP by developing a LEED-PDRI framework and applying it to a case study. The authors investigated how the application of LEED aids in identifying the scope definition of building projects and ultimately, addressing the shortcomings of the PDRI tool for buildings. Nevertheless, there remains a gap in implementing and correlating sustainable infrastructure projects to FEP tools. This research addresses such a literature gap by investigating how the Envision™ rating system aids in comprehensive FEP of sustainable infrastructure projects.

I.4.3. The Envision™ Rating System

The Envision™ rating system was developed in a partnership between the Institute for Sustainable Infrastructure (ISI) and the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design. This rating system was created to address the commonly overlooked and underfunded infrastructure projects (ISI 2018). Envision™ works as a framework that entails a holistic procedure for all types of infrastructure projects. It consists of specific guidelines within the five categories: Quality of Life (QL), Leadership (LD), Resource Allocation (RA), Natural World (NW), and Climate and Resilience (CR). Table 1 presents these categories and their corresponding subcategories with their maximum reachable amount of points (Source: ISI 2018). There are 64 sustainability and resilience indicators or "credits" within this framework, and each one of them represents the rating scale of possible performance goals: improved, enhanced, superior, conserving, and restorative. By assessing achievement through these indicators, stakeholders can address their performance and be challenged to pursue higher levels of improvement. This rating system is intended to help all stakeholders, including the communities involved in the project, to change the way that infrastructure projects are designed, planned, constructed, and operated (ISI 2018). A list of all Envision™ categories and credits can be found in Appendix C.

Table 1. Highest weighted Envision™ Categories and Subcategories.

Category	Subcategories	Max. Points	
Quality of Life (QL)	Wellbeing	92	200
	Mobility	44	
	Community	64	
Leadership (LD)	Collaboration	72	182
	Planning	60	
	Economy	50	
Resource Allocation (RA)	Materials	66	196
	Energy	76	
	Water	54	
Natural World (NW)	Sitting	82	232
	Conservation	78	
	Ecology	72	
Climate and Resilience (CR)	Emissions	64	190
	Resilience	126	
TOTAL POINTS			**1000**

There are five different levels of achievement in the Envision™ rating system: Improved (performance above conventional); Enhanced (performance adheres to Envision™); Superior (high-level performance); Conserving (a performance with zero impact); and Restorative (a performance that restores systems). Each credit has different levels of achievement according to the nature of the credit. Each category also has the opportunity to obtain higher points with innovation criteria through bonus credits called "Innovate or Exceed Credit Requirements". According to ISI (2018a), the achievement levels are assessed and weighted based on three factors: (1) the impact of the sustainability credit, (2) the adversity of the specifications required, and (3) the demonstrable impact. Also, the Envision™ v3 process includes a third-party verification process and awards program for recognizing the project achievements in sustainability. The four award levels that infrastructure projects can achieve based on a percentage of applicable points earned (max. 1000 points) are Verified (20% to 30%), Silver (30% to 40%), Gold (40% to 50%) and Platinum (50% or more).

When comparing Envision™ to other sustainable infrastructure rating systems (i.e. Greenroads, BE2ST-in-Highways, INVEST, etc), its advantage is noticeable because it addresses and certifies the widest range of infrastructure projects: roadways, water treatment, energy generation, landscaping, information systems, and more (Clevenger et al. 2013). In terms of cost savings, it may seem difficult to achieve when applying the Envision™ framework. However, based on ISI (2016) and Huang (2014), there are higher probabilities of achieving increased long-term profitability on Envision™ projects, particularly in regards to anticipating limited maintenance activities as well as controlled operational requirements and running costs. Vandebergh et al. (2016) highlighted that it is critical to start pursuing the Envision™ certification as early as possible i.e. during the Front-End Planning (FEP) phases, so there is more broad and effective collaboration between stakeholders and higher ability to make changes at little to no cost. Likewise, Weerasinghe et al. (2007), recommended that the overall cost of the project, including any sustainability rating system certification, must be identified and mitigated during the FEP stage.

Klakegg (2009) listed some of the reasons why sustainability is seldom integrated into construction project management: faulty economic benefits, high investments, lack of stakeholders commitment, multiple changing conditions, and poor scope definition. Moreover, when construction companies do decide to pursue a sustainable project, they are mostly focused on vertical construction (residential and commercial projects), leaving civil infrastructure projects behind. Despite the large investments needed for infrastructure projects, enhanced performance can be reached if sustainability criteria are integrated as part of the entire project management process (Kivilä et al. 2017). Although Envision™ is applicable at any point during an infrastructure project's lifecycle, to date the Envision™ rating system has not been integrated nor aligned with any of the evidence-based Front-End Planning tools (i.e. PDRI). This idea is slightly presented as a recommendation in the Envision™ v3 manual, when multiple applicable phases for the Envision™ framework are listed: design, construction, operations and maintenance, communication and education, and building future sustainability. The manual presents the graph illustrated in Figure 2, which tries to encourage project teams to plan, manage and consider any sustainability criteria at early stages (i.e. FEP), when the ability to influence the overall sustainability of the project increases while the cost to do so decreases (ISI 2018).

In addition to the sustainable infrastructure rating system, ISI allows professionals to obtain a sustainability credential as Envision™ Sustainability Professionals (ENV SP). This accreditation works as a training tool for project teams to use Envision™ collaboratively as well as an approach to engaging more people in sustainability.

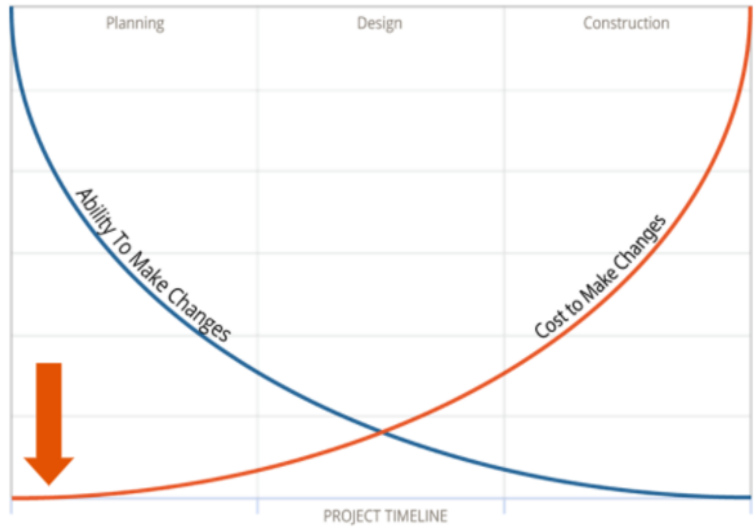

Figure 2. Cost vs Project Timeline. (Source: ISI 2018a)

I.5. Methodology

This thesis will be divided into five different Chapters. Chapter II, III, and IV are currently under review in conferences. The details of each chapter are discussed below.

Chapter I presents a thorough discussion about the motivation and background of this study. It provides a brief description of Infrastructure Projects, Front-End-Planning, the Project Definition Rating Index, Sustainable Infrastructure, and the Envision™ rating system. It also lists the objectives, research questions, and the hypothesis of this study.

Chapter II consists of evaluating the student's perception of coupling FEP practices with sustainability considerations on infrastructure projects. To accomplish this, 47 undergraduate and graduate STEM students were surveyed at FIU's College of Engineering and Computing. In this survey, the students were asked about their knowledge and familiarity with different FEP stages and sustainability for infrastructure projects, as well as custom demographic questions. The students were also surveyed about their interest in integrating FEP and sustainable infrastructure systems into the STEM curricula. It is important to notice that the surveys were implemented as a pre- and post-course activity where the students were presented with a Problem Based Learning (PBL) situation. This way, the results showed how the responses vary after the students are presented with a real-life example. The obtained data is analyzed through a paired t-test and a Wilcoxon signed-rank test, then they are graphically represented with box plots. The findings of this research reveal that students believe FEP and sustainability of infrastructure projects are extremely important topics that need to be discussed in STEM curricula. This chapter is under review for the 2021 American Society for Engineering Education (ASEE) conference.

Chapter III presents a manual analysis of each Envision™ credit to establish relationships and develop correlations between Envision™ and both infrastructure PDRIs. The analysis was then presented in a conceptual matrix, based on Weerasinghe et al. (2007), that correlates PDRI tools for infrastructure projects with Envision™ credits. This matrix provides a reasonable and reliable nexus between Envision™ and PDRI framework detailing the level of scope definition of sustainable infrastructure projects. This method is considered a strong approach for the research since it has been implemented in other studies with similar objectives, and it allows a simple and intuitive look at the correlation between each element of both tools (PDRI and Envision™). This chapter has been divided into three sections to address both infrastructure PDRIs and support the obtained frameworks through case study surveys. The first part analyses Envision™ and Section I of the PDRI-Infrastructure, the second one studies Section II of PDRI-Small Infrastructure and Envision™, and the last part works as a supporting assessment of the developed frameworks. This chapter is under review for the Canadian Society for Civil Engineering (CSCE) 2021 Annual Conference.

Chapter IV has the intent of downsizing the Envision-PDRI frameworks obtained in Chapter III, as a handier and useful approach for the industry. This chapter is divided into two major sections: (1) the elaboration of an Envision-FEP framework that correlates twenty Envision™ credits with six PDRI elements, and (2) an statistical analysis to identify the factors that impact the coupling of Envision™ and FEP. During this process, more than 100 stakeholders were surveyed. The results of this chapter helped the author in developing a precise and scaled-down framework that will help project stakeholders identify the strengths and weaknesses of a sustainable project before pursuing it. This chapter is under review for the 2022 ASCE Construction Research Congress (CRC).

Chapter V presents a summary of the study, including the study's limitations, contribution to knowledge, and possible future studies. It also provides the author's analysis and explanation of the entire research.

Figure 3 presents the research thesis overview.

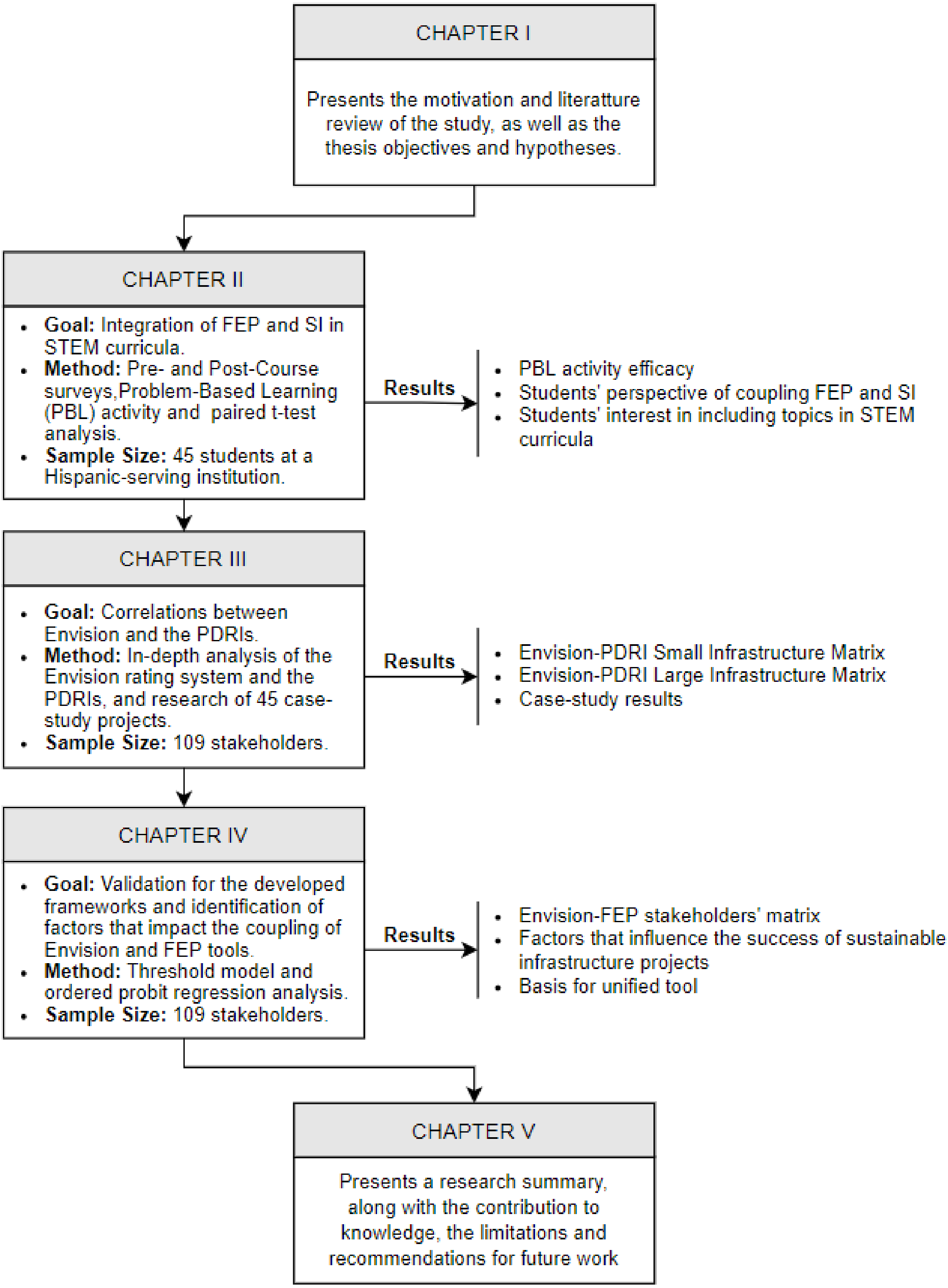

Figure 3. Research Overview

CHAPTER II

II.1. Assessing the Pedagogical Needs to Couple Front-End Planning Tools with Sustainable Infrastructure Projects

Climate change and global warming are two phenomena that are driving new construction to be sustainable, which introduces a new challenge not only in the design of these projects but also in the construction and operation phases. Due to the rapidly advancing technology and novel management tools, there is a new need for construction projects with improved project performance and fewer environmental and social impacts. To accomplish this, proper sustainability and management tools must be integrated into science, technology, engineering, and mathematics (STEM) curricula. Although some research has focused on analyzing the correlation between sustainability and pre-project planning for building projects (Weerasinghe et al. 2007), there is still a gap in coupling sustainability practices with Front-End Planning (FEP) for infrastructure projects, and introducing them into STEM education.

Nowadays, sustainability concepts have become more vital among the architecture, engineering, and construction (AEC) industries. ASCE explains the importance of sustainability and its integration in colleges and universities in its publication *The Vision for Civil Engineering in 2025* (ASCE 2007). With similar goals, the Institute for Sustainable Infrastructure (ISI) was created in 2011 to develop a new sustainable rating system that would focus solely on infrastructure projects. This rating system, named Envision™, also allows professionals to obtain a sustainability credential (ENV SP) to certify their knowledge on how to apply the Envision™ framework and concepts to their daily work. However, infrastructure projects have typically been left out of sustainable construction and teaching efforts, which may be due to the many additional challenges that integrating sustainability into an infrastructure project can represent.

To this end, there is a critical need for including FEP and sustainability concepts in STEM pedagogy, not only for building projects but also for all civil infrastructures. Flintsch et al. (2004), identified that there are many reasons for the lack of undergraduate and graduate students' interest in infrastructure management (IM) (Flintsch et al. 2004). One of the main reasons the authors acknowledged is that the students do not have sufficient exposure to IM in the early phases of civil engineering/construction management curricula. Therefore, in order to build more efficient, resilient, and successful infrastructures in the United States, the resolution process should start from the very bottom: the students, that constitute the nation's future workforce. However, STEM students are seldom exposed to FEP and SI tools and STEM instructors need to integrate such topics in construction management (CM) curricula to help them transition smoothly in their professional careers to plan, manage, and deliver infrastructure projects efficaciously and sustainably.

To highlight the importance of Front-End Planning (FEP) and sustainable infrastructure (SI) to students, the author embraced a problem-based learning (PBL) approach. PBL started as an alternative teaching method where students were presented with open-ended problems and complex questions (Elzomor et al. 2018b; Forcael et al. 2015). PBL can help students get involved in problems that mimic real-life scenarios and allows them to be more collaborative and reasonable, as well as encourages students to think critically and participate in research (Prieto et al. 2008). Additionally, research indicates that a PBL approach may be a very effective tool to improve student's learning skills and engage them in complex problem solving (Shepherd and Cosgrif 1998; Tomkinson et al. 2008). In fact, it has been demonstrated that PBL activities are very effective among CM students, and can also be successful if integrated into other majors (Pradhananga et al. 2020). Furthermore, Hurtado and Sullivan (2014) developed a dynamic model of pre-project planning in construction education as a need for more effective project plans. The model included key areas such as risk mitigation and proactive scheduling. The results showed that, compared to traditional education, the dynamic model helps professionals to pre-plan and consequently has positive impacts on the project's performance (Hurtado and Sullivan 2014). However, these studies have been inclined towards building construction and not infrastructure projects.

The current construction and engineering industry is looking for a more innovative workforce with an understanding of more than the typical technical concepts. Young engineers need to have more communication and social skills, as well as an economic and management perspective that most engineering courses do not present (Beder 1999). Previous research has integrated IM into engineering curricula by developing courses that give the students a new understanding of civil infrastructures with economics, finance, management, and public policy perspectives (Amekudzi et al. 2000). However, there is a gap in the literature that explores ways to integrate and teach sustainability for infrastructure projects in STEM curricula. To this end, past studies (McWhirter and Shealy 2018, 2020) have developed a case-based module and a flipped-classroom approach to teach sustainability of infrastructure projects and decision-making. The authors indicated that, based on students' perception of sustainable infrastructures, such a module should be more than a one-module course, and should be meshed into all civil engineering and construction curricula. The authors also concluded that there is a pressing need for a better foundation of sustainability concepts and that students recommend this topic to be more "popular" within professors and widespread in the undergraduate and graduate civil engineering curriculum (McWhirter and Shealy 2018, 2020). One particular research study implemented FEP tools (PDRI for infrastructure projects) in a lower-division construction management course, and an upper-division civil engineering course. These tools helped students broaden their understanding of the scope of an actual engineering and construction project. Additionally, the authors of the study also introduced sustainability concepts into both courses through a PBL framework, allowing students to engage in real-world sustainability projects (Elzomor and Parrish 2017). However, studies have seldom discussed the nexus between FEP and sustainability for infrastructure projects, and how an educational approach may prepare the future workforce with skills in such new practices.

Thus, this chapter integrates a PBL activity in Construction Management (CM) curricula to assess STEM students' understanding and knowledge of FEP tools as well as the sustainability of infrastructure projects. This study also evaluates the necessity of integrating these topics into STEM curricula to produce more skilled and holistic engineering and construction professionals. The PBL activity is an effective approach that facilitates students to quickly understand the importance of incorporating sustainability concepts into construction, not only for buildings but also for infrastructure projects, and how FEP techniques can also help the adequate decision-making for these projects.

II.1.1. Methodology

This chapter addressed research Hypothesis #3 by (1) examining the efficacy of the applied PBL activity in terms of improving students' knowledge and ability to work with FEP and SI tools, (2) assessing the student's perspective on the convenience of coupling FEP and sustainability for infrastructure projects, and (3) determining the student's level of interest in including novel topics like FEP for infrastructure projects and SI in the STEM curricula.

This section presents the framework used in this chapter and its implementation on a Construction Management (CM) course at Florida International University. This course, BCN 4570/BCN 5585 Sustainable Approach to Construction and Sustainable construction, mostly focuses on sustainable vertical construction. The author developed a module that involved the participation of 45 students during the CM course in the Fall 2020 semester. The module was divided into three phases. The first phase comprised a brief introduction about FEP and a SI rating system (Envision™) to the students. This phase also included a pre-course evaluation survey that recorded students' comprehension of SI and FEP tools for infrastructure projects. The students were also asked about their interest in including FEP and sustainability criteria for infrastructure projects in the STEM curriculum, as well as their socio-demographic profiles. During the second phase, the students participated in a Problem-Based Learning (PBL) activity that simulated a real-work environment situation. In phase three, a post-course evaluation survey was conducted with the students, with the same questions from the pre-course questionnaire. The pre- and post-course surveys identified the variation in the students' knowledge and measured the effectiveness of the PBL activity in the CM course. The author matched the data from both surveys through one unique unanimous personal identification code (the last three numbers of the student's cellphone number + the first three letters of the city they were born).

The content of the module focused on: (1) importance and effectiveness of defining the scope of a project at an early stage (FEP); (2) importance of sustainability concepts not only for buildings but also for civil infrastructure projects; (3) the advantages of incorporating sustainability criteria as early as possible in a project, i.e., at the FEP phase; and (4) benefits of understanding and implementing FEP and SI practices in AEC projects. The module was partially developed based on courses and studies established by the Construction Industry Institute (CII) and the Institute for Sustainable Infrastructure (ISI) (CII 1997, 2006; Elzomor et al. 2017; Gibson et al. 2010). The PBL activity presented the students with a real-life work situation where they needed to act as if they were working for a development firm that was interested in developing a transportation system in Miami, Florida. The students needed to plan a proposal that connected between east-west and north-south of Miami. Then, students were divided into seven groups and were instructed to assign roles between them, such that each one of them would have a different position, i.e., designers, contractors, subcontractors, consultants, and engineers. The idea of defining these group meetings was to show the students how charettes are conducted at the beginning of a project, where all stakeholders must be aligned towards the same objectives. They were allowed to have a first 10-minute meeting to discuss their initial proposal where they should include all general considerations for the infrastructure project presented (location, schedule, cost, resilience, resources). Then, they had 2 minutes for each group to present their proposal and answer some questions related to the stakeholders' responsibilities, the scope of the project, and the risks that it represented. After that, they were allowed to have a second 10-minute meeting to add any other useful information and to consider aspects that they had previously not taken into account. Then, each group had again 2 minutes to present. Important topics were discussed including value engineering procedures, local resources, and materials, compliance requirements, etc. All these topics were specifically selected as they are important elements in the FEP Project Definition Rating Index (PDRI) tools developed by the CII and the Envision™ rating system (CII 2012; ISI 2018). Figure 4 illustrates the content of the module, the objectives, the instruments used to evaluate each objective, and the type of analyses implemented.

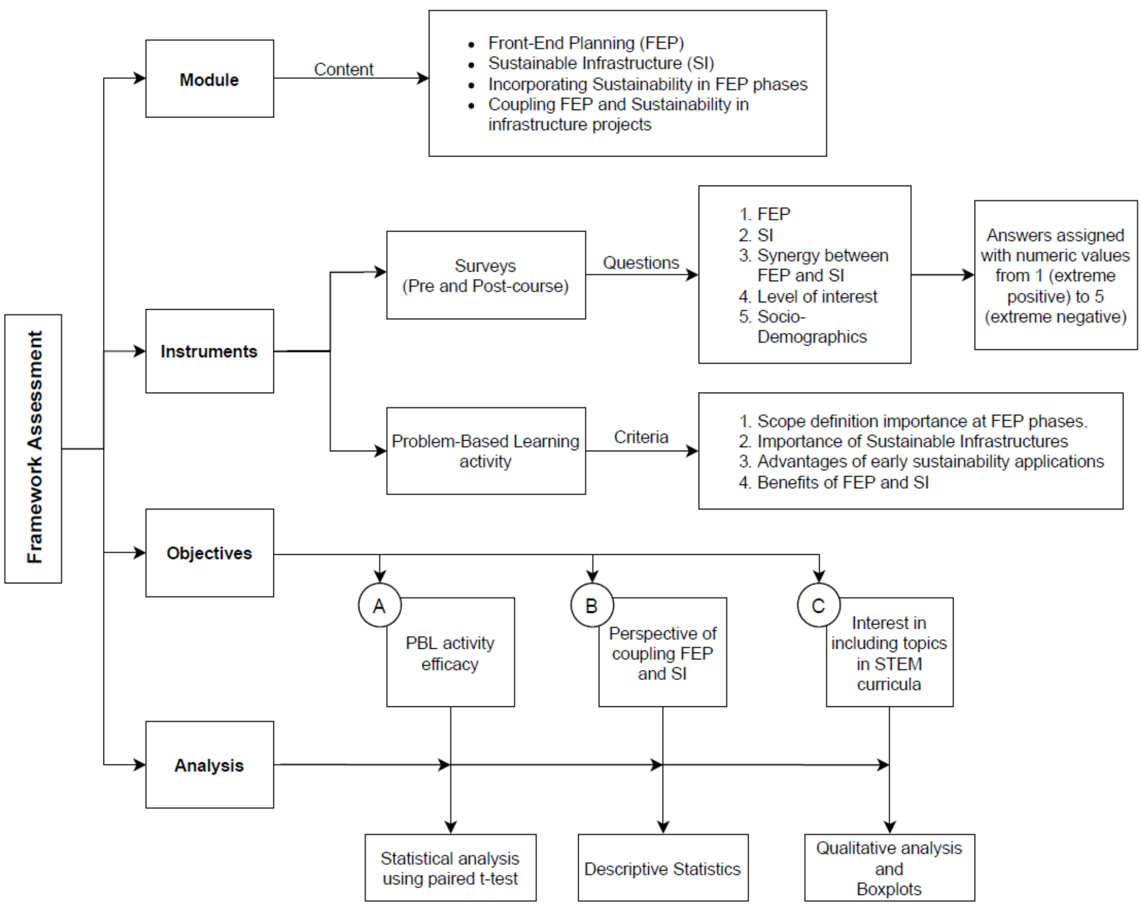

Figure 4: Chapter II Overview

To easily understand the student's actual knowledge of these novel topics, the pre- and post-course surveys covered five different areas: (1) Front-End Planning, including scope definition, risk assessment, and team alignment; (2) Sustainable Infrastructures, including sustainable rating systems and the importance of infrastructure projects to the built environment; (3) the possible synergy between FEP and SI; (4) students' level of interest towards incorporating FEP and SI into STEM curricula; and (5) general socio-demographic questions to learn about the student's background, status, and future working expectations. The possible answers to the questions were assigned with numeric values, usually 1 to 5, 1 being the most positive and 5 the most negative as shown in Figure 5.

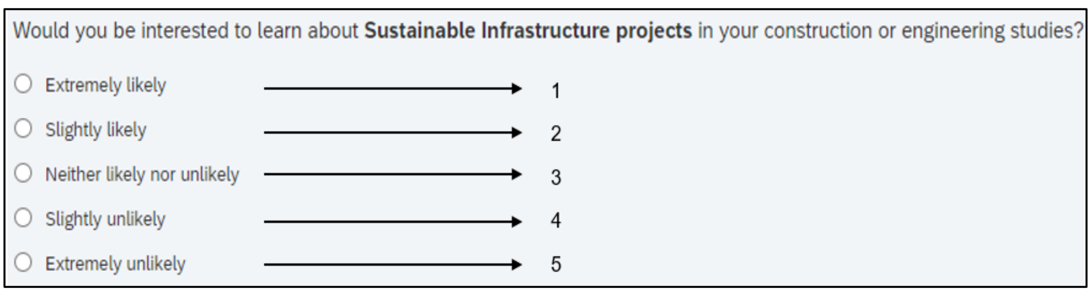

Figure 5: Example of a survey question

The module addressed three research questions focused on identifying: (1) What are the strengths and weaknesses of the PBL activity in terms of improving students' knowledge and ability to work with FEP and SI tools?; (2) What are the student's opinions on the convenience of coupling FEP and sustainability for infrastructure projects? (3) What is the student's level of interest in including FEP for infrastructure projects and SI in the STEM curricula?

The author evaluated the pre- and post-course surveys to analyze the effectiveness of the PBL activity and the students' perspectives about FEP and SI. The pre- and post-course survey responses were compared and analyzed through a paired t-test and a Wilcoxon signed-rank test in SPSS. A paired t-test, or dependent sample t-test, is a parametric test used to find if there is a mean difference between two variables for the same subject. And, a Wilcoxon signed-rank test, is a nonparametric test used to find if the mean difference between the two variables is 0. In this case, the study aims to determine whether or not there is a significant difference in mean value in the students' ratings after integration of PBL activity. The author utilized SPSS to conduct the Wilcoxon signed-rank test and the paired t-test analysis with a confidence interval set to 95% and the maximum desired P-value of 0.05.

II.1.2. Results

This section presents the results of Chapter II analyses and determines: (1) the efficacy of the PBL activity through a paired t-test analysis in SPSS; (2) the perception of CM students in a Hispanic-Serving Institution concerning the convenience of coupling FEP for infrastructures and SI through qualitative descriptive analysis; and (3) the student's level of interest in including FEP for infrastructure projects and SI in the STEM curricula. The students targeted through this research were 45 registered students at Florida International University and consisted of 31 male and 14 female students, with more than half of the students currently working in the industry and with 23 years or older, as shown in Figure 6.

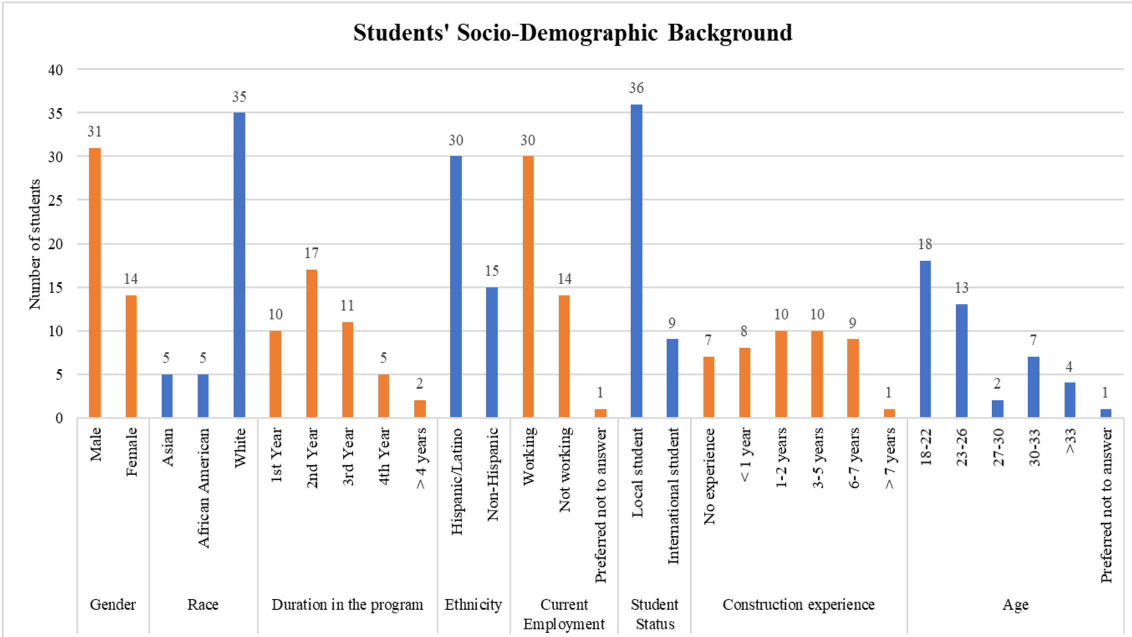

Figure 6: CM students' socio-demographic background information.

II.1.2.1. Effectiveness of Problem-Based Learning Activity

II.1.2.1.1. Paired t-test

To identify the effectiveness of the applied PBL activity, a paired t-test was conducted using the pre- and post-course survey data. To ensure the quality of the results on a paired t-test, the dependent variable must be continuous and should be approximately normally distributed. Therefore, a normality test was initially performed where most of the data satisfied the conditions of normalization of data to proceed with a paired t-test. As shown in Table 2, a p-value of less than 0.05 was obtained for almost all variables indicating that there is a significant difference in the means of the pre- and post-course results. Regarding variables 2, 4, and 9, results indicate a p-value of more than 0.05, meaning that the PBL activity didn't change the student's perspective significantly in those aspects. The obtained results of the analysis indicated that the Problem-Based Learning framework was effective in terms of (1) increasing the student's familiarity with project scope definition; (2) allowing students to learn about the importance of early meeting with all project stakeholders; (3) helping students to differentiate between Front-End Planning and traditional planning processes; (4) encouraging students to be more familiar with FEP tools, such as risk and change management; and (5) increasing the knowledge about infrastructure projects and their importance to the built environment.

Table 2: Paired t-test analysis for the effectiveness of the PBL activity (n=45)

V.N	Variables	Absolute Mean Difference	t	Degree of Freedom	p-value
1	Familiarity with project scope definition	0.200	2.449	44	<0.05
2	Defining the project scope before construction	0.044	0.443	44	>0.05
3	Project stakeholder's early involvement	0.222	2.028	44	<0.05
4	Importance of team alignment	0.089	0.813	44	>0.05
5	Difference between FEP and traditional planning	0.511	4.206	44	<0.05
6	Familiarity with FEP tools	1.067	5.347	44	<0.05
7	Knowledge about infrastructure projects	0.578	5.144	44	<0.05
8	Importance of infrastructure projects	0.400	3.438	44	<0.05
9	Familiarity with sustainability and sustainable construction	0.200	1.773	44	>0.05

A presentation of a real-life work scenario to the students allowed them to have a better understanding of how Front-End Planning is conducted during a project. The students not only discussed the best options and proposals within their group, but they also had the opportunity to listen to the other groups' ideas and the experience shared by the authors of this research. During the activity, the most important aspects of FEP were considered, including early scope definition and project team involvement. Thus, students considered that the PBL activity was helpful in terms of variables 1, 3, 5, and 6. Regarding variables 7 and 8, students' perception of infrastructure projects did improve, which may be because their CM major mostly focuses on vertical construction (buildings), so students are poorly exposed to civil infrastructure topics (Flintsch et al. 2004). The PBL activity focused solely on a civil infrastructure project so that the CM students could recognize the impacts and needs that an infrastructure project carries. It is important to notice that variable 9, related to sustainable construction, didn't show much of a difference between the pre- and post-course surveys. This may be due to that the PBL activity was implemented during a sustainable construction course, which demonstrates that the CM students already had enough knowledge of the topic.

Another way of demonstrating the effectiveness of the PBL activity was through the students' feedback. The students were asked if they considered the PBL framework changed their perception about the Front-End Planning processes of a sustainable infrastructure project. Even though the answers were widespread between ranks of likely and unlikely, most of the class (96%) voted for extremely likely, slightly likely, and neither likely nor unlikely. A small portion of the students (4%) didn't consider a change of perspective through the activity presented, which was expected since some of the students already had sufficient knowledge on the topics before the activity. However, the objective of this research was accomplished, and the majority of the students did obtain new valuable knowledge and skills that are helpful for their future development. The framework presented in this paper has been demonstrated to be beneficial in different courses since the PBL approach allows students to amplify their knowledge through real-life problem experience (Lopez et al. 2000). Additionally, PBL activities are proven to be successful and show promise for future implementation across multiple disciplines and institutions (Elzomor et al. 2018b).

II.1.2.1.2. Wilcoxon signed-rank test

Another statistical approach used in this study was a Wilcoxon Signed-Rank test, which is a nonparametric test used for paired data (i.e., pre- and post-surveys). This test is implemented “to test the hypothesis that the median difference between the absolute values of positive and negative paired differences is 0” (Harris and Hardin 2013). The author utilized Wilcoxon signed-rank test to analyze the Likert-scale data from the PBL activity. Similar to the paired t-test analysis, a confidence level for statistical significance was stated to 95% and the maximum desired P-value was set to 0.05.

The signed-rank test statistic is calculated as:

$$S = \sum_{i=1}^{n_r} r_i I(D_i > 0) - \frac{n_r(n_r+1)}{4} \tag{1}$$

Where $I(D_i > 0)$ is an indicator function that the ith difference is positive, n is the number of observations, and r represents the total ranks of the test (Harris and Hardin 2013).

The analysis results showed in Table 3 list the absolute mean difference, the standard deviation values and the minimum and maximum scores for each of the variables, during the pre- and post-course surveys. Additionally, as shown in Table 4, the variables with a p-value of less than 0.05 are considered statistically significant so the null hypothesis can be rejected. The absolute mean difference between the pre- and post-survey results show a significant improvement in students’ knowledge and skills, which aligns with the paired t-test results and the same conclusions can be assumed.

Table 3. Descriptive statistics of Wilcoxon signed-rank test (n=45)

VN	Variables	Absolute Mean Difference	Std. Deviation	Minimum	Maximum
1 - Pre	Familiarity with project scope definition	0.578	0.657	1	3
1- Post			0.580	1	3
2 - Pre	Defining the project scope before construction	0.022	0.659	1	3
2 - Post			0.723	1	4
3 - Pre	Project stakeholders early involvement	1.289	0.621	1	3
3 - Post			1.014	2	5
4 - Pre	Importance of team alignment	1.178	0.793	2	5
4 - Post			0.919	1	4
5 - Pre	Difference between FEP and traditional planning	0.533	0.763	1	4
5 - Post			0.599	1	3
6 - Pre	Familiarity with FEP tools	0.133	0.529	1	3
6 - Post			0.471	1	3
7 - Pre	Knowledge about infrastructure projects	0.578	0.522	1	3
7 - Post			0.701	1	3
8 - Pre	Importance of infrastructure projects	0.089	1.069	1	5
8 - Post			0.720	1	4
9 - Pre	Familiarity with sustainability and sustainable construction	0.378	0.688	1	3
9 - Post			0.804	1	4

Table 4. Wilcoxon signed-rank test statistics results

VN	1	2	3	4	5	6	7	8	9
Z	-2.32	-0.45	-1.97	-0.83	-3.41	-4.18	-4.06	-3.08	-1.76
Asymp. Sig. (2-tailed)	0.02	0.66	0.05	0.41	0.00	0.00	0.00	0.00	0.08
p-value	<0.05	>0.05	<0.05	>0.05	<0.05	<0.05	<0.05	<0.05	>0.05

II.1.2.2. The convenience of coupling FEP and SI

This section is focused on civil infrastructure projects and highlighted the importance of integrating Front-End Planning (FEP) and sustainability techniques into these projects. To this end, the students were initially asked multiple-choice questions to determine their current knowledge and interest in infrastructure projects. A second set of questions covered sustainability criteria for infrastructure projects and FEP techniques. Finally, the questionnaire correlated FEP and SI to identify possible synergies between the topics. All these sections resulted in quantitative data.

First, the questions covered the future working interests of the students. The responses showed that 33% of the class wanted to dedicate themselves to commercial projects, 21% to residential projects, 14 % to infrastructure projects, another 14% to multi-use projects, 8% to entertainment projects, and the remainder wasn't sure yet [Figure 7 (b)]. Second, the students were asked the type of companies they would prefer to work for upon graduation. 60% of the students would like to work for a construction company, while only 4% of the class stated their interest in working for a government organization [Figure 7 (a)]. This means that the students would most likely continue their careers in building project management since the majority of civil infrastructure projects are carried out by governmental and public agencies, i.e. the U.S. Department of Transportation. Finally, students were asked about their working experience in infrastructure projects. Only eight students stated that they had worked on an infrastructure project before, while 16 had a fair idea about these types of projects and the rest had almost no knowledge on the topic. Previous studies have highlighted that students are seldom aware of infrastructure projects due to lack of dissemination of concepts in formal Construction Management (CM) education, poor career advancement opportunities, and more attraction toward urban-based projects like commercial and residential development (Flintsch et al. 2004). Thus, the low percentage of students' interest in infrastructure projects in this study indicated that more effort is required from academia to better prepare the future STEM workforce. Additionally, the CM curriculum needs to integrate innovative pedagogical approaches such as PBL to improve engagement in such topics as well as enhance their critical thinking ability.

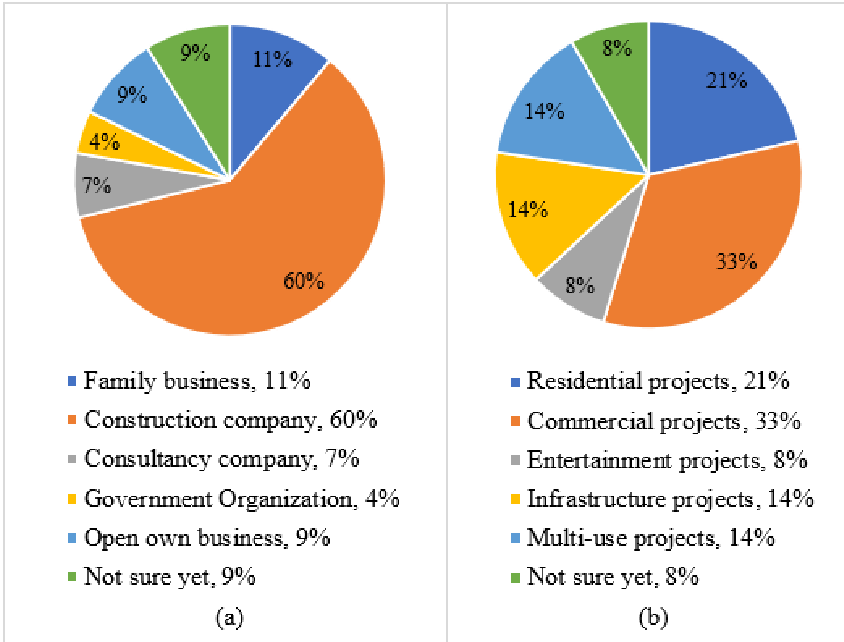

Figure 7: (a) type of company that students would prefer to work for upon graduation; (b) type of projects that students would prefer to work on upon graduation;

Regarding the sustainability of infrastructure projects, the survey first investigated the students' awareness of sustainable construction; and, as was expected, they all confirmed they were familiar. Next, the questions related to the students' familiarity with sustainable rating systems. As expected, more than 80% of the students were aware of the Leadership in Energy and Environmental Design (LEED) rating system since BCN 4570/BCN5585 is mostly oriented to this topic. Only a few of the students indicated that they also knew other sustainable rating systems: three students were knowledgeable about GreenRoads, six about the Living Building Challenge, and one about INVEST. It is worth noting that, before the PBL activity, many students were unaware of the Envision™ rating system for Sustainable Infrastructure (SI) and showed very little knowledge of civil infrastructure projects. Then, the students were asked if they would implement sustainability criteria during the design, construction, and operation of an infrastructure project. And, despite the shortage of civil infrastructure knowledge on the CM students, more than 80% of them agreed that there is significant importance in integrating sustainability criteria into these projects.

During the intervention, the PBL activity introduced students to several different FEP elements that are critical to be assessed in the project design phase. Since the activity involved a real-project scenario to disseminate knowledge about FEP elements, 13 students who were not aware of FEP tools reported that such elements are critical for infrastructure project design. Thus, the activity provided a better understanding of FEP elements and tools such that more than 80 % of students showed that they would include multiple FEP elements before the project's design phase, meaning that they did understand the importance of FEP in any project after the PBL activity (Figure 8).

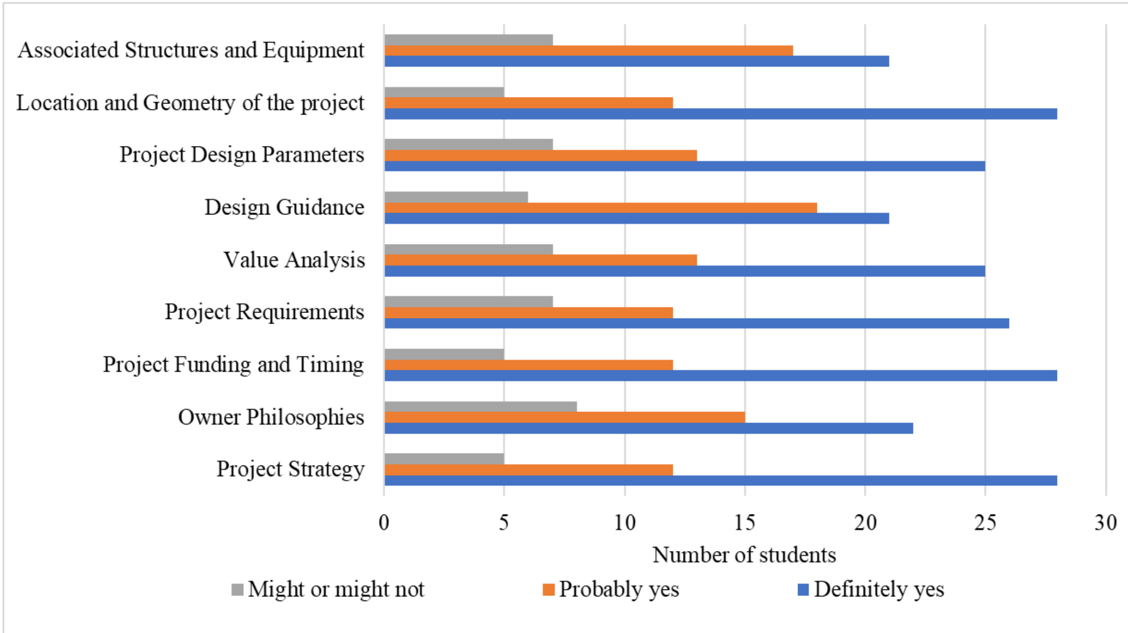

Figure 8: students' answer in whether to define the listed elements before the completion of a project's design.

Finally, with the intent of coupling sustainability criteria with FEP practices for infrastructure projects, the questionnaire tested the students' judgment on this synergy. Students' considered that defining the scope of a project before a project's kickoff meetings can significantly improve its success, but sustainability considerations must also be included in the early stages. Besides, almost all students (98%) indicated that applying sustainability criteria to a project, can support its performance, in terms of cost, schedule, and change orders [Figure 9 (a)]. Moreover, after participation in the PBL activity, students were more aware of FEP principles since many students reported that all project stakeholders, including communities affected by the project, should be involved very early in the project as shown in Figure 9 (b). These responses and the class performance on the PBL activity answered the second research question: the students do consider that fostering an early relation between FEP practices and sustainability criteria can enhance an infrastructure project's performance and help achieve the sustainability goals.

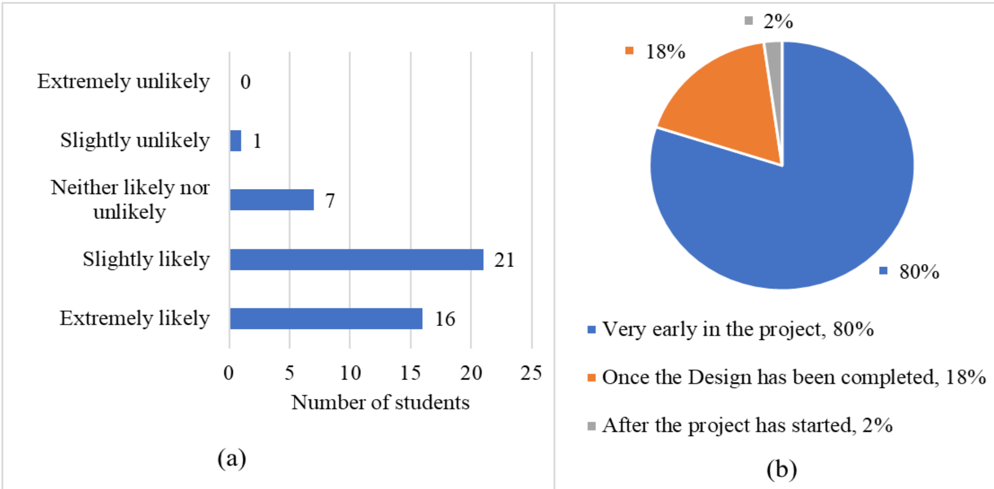

Figure 9: (a) students' perception on how likely sustainability criteria can support a project's performance in terms of cost, schedule, and change orders, n=45; (b) students' perception of when in a project should all stakeholders be involved, n=45

II.1.2.3. Integration of FEP and SI in STEM curricula

This section is comprised of the students' perception of integrating FEP for infrastructure projects and SI in the STEM curricula. The students' aspirations regarding this topic were collected with the help of open-ended questions, which resulted in qualitative data. More than 84% of the class indicated an interest in including Sustainable Infrastructure (SI) and Front-End Planning for infrastructure projects in their studies. Most of the students (64%) agreed that their curricula should include these topics as a portion of a course, while a smaller amount (24%) agreed that FEP for SI could be included as a complete course in the curricula. Additionally, students were allowed to rate their level of interest from 1 to 5 (1 being not interested and 5 being extremely interested) to include three different tools and techniques in their STEM curricula: (1) Sustainability for infrastructure projects, (2) Front-End Planning for infrastructure projects, and (3) Infrastructure Engineering Management. Boxplots were created using R-Studio to showcase the students' level of interest in integrating these techniques, as shown in Figure 10. It can be inferred from Figure 10 that the majority of the students are interested in integrating all these topics into their curricula. Additionally, students showed the most interest in learning more about Sustainability for Infrastructure Projects, with over half of the population selecting "highly interested" or higher. The latter result is possibly due to climate change and renewable resources, which are typically associated with sustainability, being more of a household topic of conversation.

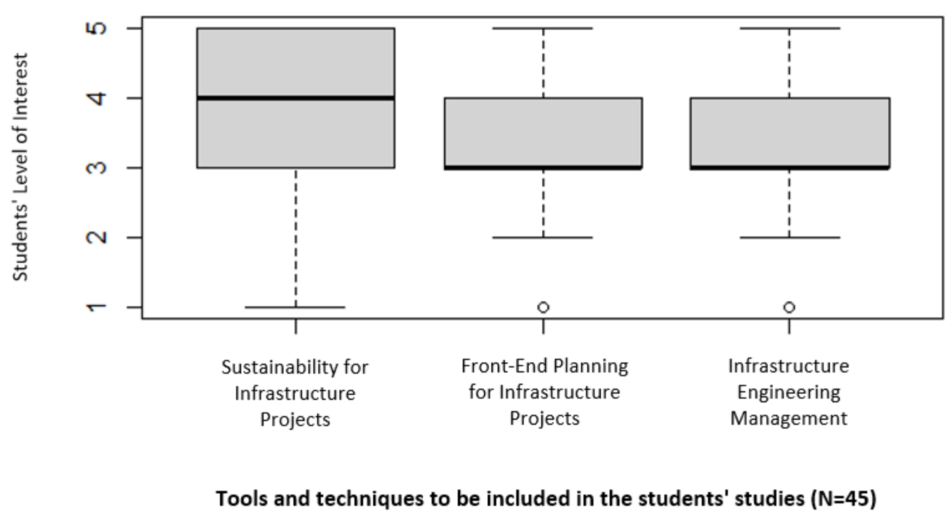

Figure 10: Boxplots of the students' level of interest in incorporating different techniques in their studies. Being 1=Not interested, 2=Probably interested, 3=Interested, 4=Highly Interested, and 5=Extremely Interested.

Lastly, this research also investigated the different types of novel practices being implemented by the students' current employers. It can be observed from Figure 11 that most companies have adopted various FEP strategies in their projects, i.e. change management and risk assessment tools, while only 9% of those companies have integrated sustainability certifications. Recent studies have shown that members of the STEM workforce, who have an Envision™ credential (ENV SP), tend to present a more positive attitude towards the integration of sustainability criteria in infrastructure projects (Bradford et al. 2017; Contreras and Gloria 2017; ISI 2018; Nelson 2014). Since the results show that the number of companies adopting sustainability certification is significantly low, integration of such concepts early on in STEM courses can help increase the number of certified sustainable projects in the US. Moreover, according to other results in this research, students do have a high interest in learning more about sustainability for infrastructure projects, and not only for vertical construction. Meaning that the lack of sustainable infrastructure projects in the US may derive from poor sustainable education.

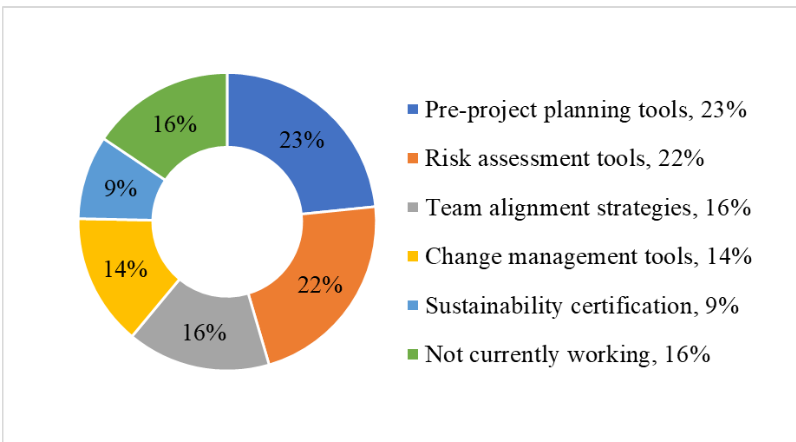

Figure 11: novel practices implemented by the student's current company.

Front-End Planning is a process that stakeholders can follow to develop sufficient strategic information, mitigate risks, make the appropriate decisions to maximize the chance for a successful project. Good FEP can result in 10% cost avoidance, 7% shorter schedules, and 5% change reductions (CII 2006). Therefore, introducing FEP to infrastructure projects that pursue a sustainability certification can aid in additional efforts needed by these projects, during the planning, design, construction, and maintenance phases (Weerasinghe et al. 2007). FEP practices and SI, when individually integrated, ensure enhanced performance in infrastructure projects and can potentially lead to greater success when considered together. Students, both undergraduate and graduate, can benefit from learning these concepts, as well as help infrastructure projects to be more effective and sustainable (McWhirter and Shealy 2020; Amekudzi et al. 2005).

II.2. Chapter II Conclusions

This chapter presented a Problem-Based Learning (PBL) activity within 45 undergraduate and graduate CM students at a Hispanic Serving Institution to assess the need of integrating Front-End Planning (FEP) and sustainability techniques for civil infrastructure projects into STEM curricula.

The results of the study indicated that a few of the students had already learned about sustainability and management of infrastructure projects, while all of them had previous knowledge of building project management and sustainable building construction. However, 87% of the students believe that it is important to integrate sustainability criteria during the design, construction, and operation of an infrastructure project, and all of them agreed on the importance of an infrastructure project to the built environment and the communities. This demonstrates that even when the students didn’t have much understanding of infrastructure construction at the beginning, after the PBL activity they recognized the necessity of integrating Front-End Planning practices for Sustainable Infrastructure projects into the STEM curricula.

Indeed, participation in the PBL activity positively impacted students in different aspects: (1) it increased the student's familiarity with project scope definition and the pre-project planning process; (2) it allowed students to learn about the importance of early meeting with all project stakeholders; (3) it helped students to differentiate between Front-End Planning and traditional planning processes; (4) it encouraged students to be more familiar with FEP tools, such as risk and change management; and (5) it increased the knowledge about infrastructure projects and their importance to the built environment. 38 out of the 45 students considered that the PBL activity was helpful and did actually changed their perspective on the FEP processes of an infrastructure project. This number may be increased if the framework presented in this chapter is included during multiple opportunities and courses, instead of a single class during a whole semester.

CHAPTER III

III.1. Creating a Framework that Couples Front-End Planning with Sustainable Infrastructure Projects

Construction stakeholders are not usually aware of the societal and environmental impacts of civil infrastructure projects. Thus, they forget to adopt and implement sustainability principles, or they plan to do it at the almost end of the project where substantial investments would need to take place. Since they do not consider the Triple Bottom Line (TBL) from a social, environmental, and economic perspective, infrastructure projects are declining. Other aspects that affect the success rate of these kinds of projects are poor planning and risk management. In fact, when thinking about a sustainable project, additional efforts show up during the planning, design, construction, and maintenance phases, or better said, during the entire life-cycle of the project (Weerasinghe et al. 2007). This is because to assure the success of an infrastructure project, all phases must be taken into account and the important decisions should be considered from the very beginning, i.e. at the Front-End Planning (FEP) phase prior to authorizing the project's funding. The FEP phase of a project allows team members to develop sufficient scope definition to significantly reduce change orders and rework costs (Gibson et al. 2006). According to Olyai (2018), proper FEP and communication between stakeholders during the entire life-cycle of a project can define its success. The author studied the factors in engineering deliverables that can affect a project's cost and schedule performance and concluded that team alignment and communication were critical in all project phases. Since sustainable projects, mostly infrastructures, represent additional efforts and complexities, it is critical to implement FEP tools along with all the sustainability criteria that are needed. To this end, this chapter focuses on (1) analyzing each credit and category of the Envision™ rating system and the PDRI tools for infrastructure projects to obtain possible synergies between them, and (2) present this correlation in a conceptual matrix and validate it through case study surveys.

III.1.1. Methodology

This chapter addressed research Hypothesis #1 by studying how the Envision™ rating system aids in diligent FEP when coupling it with the PDRI tools for both small and large infrastructure projects, as well as by developing a conceptual matrix that correlates these tools. The data for the study was obtained from an in-depth literature review analysis and a survey that was conducted to 109 stakeholders. The results were then presented in conceptual matrices, which are analytical tools that provide a logical and reliable framework (Fernández-Sols et al. 2011; Weerasinghe et al. 2007) and easily demonstrate the relationship between sustainability criteria and Front-End Planning decisions.

The survey questionnaire was carried out online for more than three months. More than 100 professionals were interrogated about their work experience with infrastructure projects and sustainability certifications. The survey entailed information about the overall planning process of the projects that the respondents have worked with, as well as how a sustainability certification relates to multiple FEP processes. From the total number of respondents, 45 Envision™ certified projects were analyzed, which represents more than 60% of the number of projects awarded by Envision™ to date in the U.S.

It is important to mention that the scope definition elements used during this study were selected from two innovative FEP tools: the Project Definition Rating Index for small and large infrastructure projects. Elzomor et al. (2018a) explained in detail the differences between small and large infrastructure projects so stakeholders could choose which PDRI tool would offer a better assessment to their projects. For instance, some of the differences they listed are: (1) the total installed cost for a small infrastructure project is less than $20 Million, (2) the engineering effort for large infrastructure projects is higher than 5000 hours, and (3) the construction duration of small projects is between six to twelve months, while large infrastructure projects can take longer than 18 months to finish construction. To this end, the highest-weighted categories from each of the PDRI tools for infrastructure projects were selected for this study.

This chapter consisted of three different phases: (1) an Envision-PDRI matrix for large infrastructure, (2) an Envision-PDRI matrix for small infrastructure, and (3) sustainable infrastructure case-studies analysis. A detailed explanation of each phase can be found below.

- *Phase 1:* This phase involved analyzing each of the 59 sustainability credits in the Envision™ rating system (Innovation-related credits were excluded from this analysis), which are divided into five major categories (1) Quality of Life (QL), (2) Leadership (LD), (3) Resource Allocation (RA), (4) Natural World (NW), and (5) Climate and Resilience (CR). After understanding the intents and requirements of each sustainability credit, these were connected to 20 scope definition elements in the Project Definition Rating Index (PDRI) tool for small infrastructure projects. To this end, the most important (i.e. highest-weighted) section of this PDRI tool was analyzed. This section, called Basis of Design (BOD), evaluates processes and technical information elements for a full understanding of the engineering/design requirements necessary for a project. The BOD section accounts for 47% of the 1000 points of the PDRI-Small Infrastructure (Elzomor et al. 2017), and it is divided into four categories: (1) Design Guidance, (2) Project Design Parameters, (3) Location and Geometry, and (4) Associated Structures and Equipment. This phase establishes when, during the BOD phase, the appropriate sustainability decisions need to be made.

- *Phase 2:* This phase consisted of evaluating the existing synergies between the 59 sustainability credits and 23 scope definition elements from the PDRI tool for large infrastructure projects. These elements are included in the highest weighted section of this PDRI tool: the Basis of Project Decision (BPD), which represents 43.7% of the total 1000 points available. The BPD is the process where the project team decides the project strategy, its objectives, and requirements (CII 2013), and it is divided into five major categories: (1) Project Strategy, (2) Owner/Operator Philosophies, (3) Project Funding and Timing, (4) Project Requirements and (5) Value Analysis. This phase determines when, during the BPD phase, the appropriate sustainability decisions need to be made.

- *Phase 3:* This phase consisted of multiple case-study research to assess the importance of establishing synergies between FEP practices with sustainability criteria in infrastructure projects. The case-studies utilized in this study included only those infrastructure projects with sustainability certification (i.e. Envision™) from the survey results. The questionnaire included information regarding the approximate value of the project, the rate of success, the financial and change management performance, the strengths and weaknesses of the sustainable rating system, the challenges presented during the certification, and in which stages of the project life cycle they applied all sustainability criteria.

Figure 12 summarizes the methodology of Chapter III.

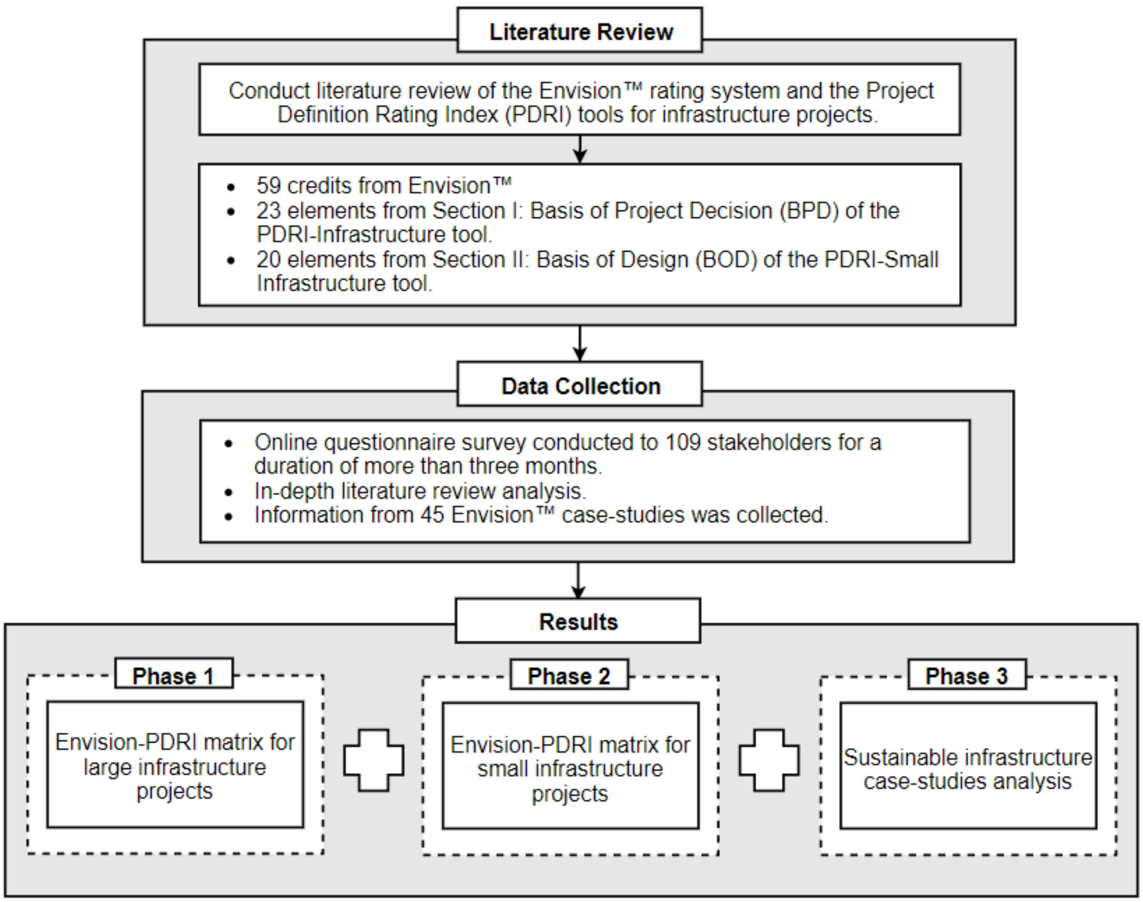

Figure 12. Chapter III overview

III.2. Results and Analysis

Detailed information on the Envision™ rating system, the PRDI-Infrastructure, and PDRI-Small infrastructure tools can be obtained from the ISI Manual (2018a), Bingham and Gibson Jr. (2010), and Elzomor et al. (2017) respectively. All elements and categories from these tools can also be found in Appendices A, B, and C. The analysis and results of this chapter are presented in the methodology phases below.

III.2.1. Phase 1: Developing framework for Basis of Design and Sustainability

This section describes in detail the matrix presented in Table 5 for Section II: Basis of Design (BOD) of the PDRI-Small Infrastructure tool, providing a better understanding of how the framework supports proper scope definition for sustainable infrastructure projects. Each sustainability credit from the Envision™ rating system has been analyzed, and the corresponding PDRI elements have been identified. This comprehensive analysis demonstrates that following sustainability certification criteria can aid in the scope definition process of SI projects. For instance, the analysis of the Envision™ Natural World (NW) category and its elements during BOD can be found below. This Envision™ category was chosen to provide an example of the analysis because it is the one with the higher amount of points within its credits in the Envision™ rating system.

- ***NW1.1 Preserve Sites of High Ecological Value:*** this credit intent is to identify areas of high ecological value and avoid placing the project in any of those areas. This credit entails decisions under the scope definition elements C.1-C.5, D.3, E.1, E.2, and E.3.

- ***NW1.2 Provide Wetland & Surface Water Buffers:*** this credit promotes the protection and restoration of wetlands, shorelines, and waterbodies. Decisions for this credit can be made under C.1-C.5, D.3, E.1, E.2, and E.3 of PDRI.

Table 5. Envision-BOD Framework

Envision™ Credits \ PDRI Basis of Design			DESIGN GUIDANCE							PROJECT DESIGN PARAMETERS						LOCATION AND GEOMETRY			ASSOCIATED STRUCTURES & EQUIPMENT			
			C.1 Lead/Discipline Scope of Work	C.2 Project Codes and Standards	C.3 Topographical Surveys & Mapping	C.4 Project Site Assessment	C.5 Environmental & Regulatory Consid.	C.6 Value Analysis	C.7 Construction Input	D.1 Capacity	D.2 Design for Safety & Hazards	D.3 Civil and Structural	D.4 Mechanical and Equipment	D.5 Electrical and Controls	D.6 Operations and Maintenance	E.1 Schematic Layouts	E.2 Alignment and Cross-Section	E.3 Control Access	F.1 Support Structures	F.2 Hydraulic Structures	F.3 Miscellaneous Elements	F.4 Equipment List
QUALITY OF LIFE	QL1.1	Improve Community Quality of Life	X								X	X									X	
	QL1.2	Enhance Public Health and Safety	X	X		X	X				X	X			X			X			X	
	QL1.3	Improve Construction Safety	X	X			X				X										X	X
	QL1.4	Minimize Noise and Vibration	X	X		X	X				X	X		X	X	X		X			X	X
	QL1.5	Minimize Light Pollution	X	X		X	X			X	X	X	X	X	X	X		X			X	X
	QL1.6	Minimize Construction Impacts	X	X	X	X	X	X	X	X	X	X		X	X						X	X
	QL2.1	Improve Community Mobility	X	X		X			X	X		X				X		X			X	
	QL2.2	Encourage Sustainable Transportation	X	X	X	X		X	X	X		X			X	X		X				
	QL2.3	Improve Access & Wayfinding	X	X		X			X	X		X				X		X			X	
	QL3.1	Advance Equity and Social Justice	X	X								X				X	X	X				
	QL3.2	Preserve Historic and Cultural Resources	X		X	X	X		X			X				X	X	X				
	QL3.3	Enhance Views and Local Character	X	X	X	X	X		X			X				X	X	X				
	QL3.4	Enhance Public Space & Amenities	X		X	X	X		X			X				X	X	X				
LEADERSHIP	LD1.1	Provide Effective Leadership & Commitment	X	X	X			X	X			X					X				X	X
	LD1.2	Foster Collaboration and Teamwork	X					X	X			X					X				X	X
	LD1.3	Provide for Stakeholder Involvement	X	X	X	X	X	X	X			X	X			X	X	X			X	X
	LD1.4	Pursue By-Product Synergy	X		X	X	X	X	X			X	X								X	X
	LD2.1	Establish a Sustainability Management Plan	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	LD2.2	Plan for Sustainable Communities	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	LD2.3	Plan for Long-Term Monitoring & Mainten.	X	X				X	X	X		X			X		X					X
	LD2.4	Plan for End-of-Life	X	X			X	X	X	X		X			X		X					X
	LD3.1	Stimulate Economic Prosperity & Develop.	X				X	X	X		X	X										
	LD3.2	Develop Local Skills & Capabilities	X									X										
	LD3.3	Conduct a Life-Cycle Economic Evaluation	X						X			X			X							X
RESOURCE ALLOCATION	RA1.1	Support Sustainable Procurement Practices	X			X		X	X			X	X		X							
	RA1.2	Use Recycled Materials	X			X		X	X		X	X	X									
	RA1.3	Reduce Operational Waste	X			X		X	X		X	X										
	RA1.4	Reduce Construction Waste	X			X		X	X		X	X										
	RA1.5	Balance Earthwork On Site	X		X	X		X	X		X	X							X			
	RA2.1	Reduce Operational Energy Consumption	X	X		X				X		X	X	X					X			X
	RA2.2	Reduce Construction Energy Consumption	X	X		X			X	X		X	X	X					X			X
	RA2.3	Use Renewable Energy	X	X		X	X	X	X	X		X	X	X	X				X	X	X	X
	RA2.4	Commission & Monitor Energy Systems	X		X					X		X	X	X	X			X	X			
	RA3.1	Preserve Water Resources	X	X		X	X	X		X		X	X									
	RA3.2	Reduce Operational Water Consumption	X	X		X	X			X		X	X		X				X	X		
	RA3.3	Reduce Construction Water Consumption	X	X		X	X			X		X	X						X	X		
	RA3.4	Monitor Water Systems	X		X					X		X	X		X			X	X			

Table 5. Envision-BOD Framework (Continued)

Envision™ Credits		PDRI Basis of Design	DESIGN GUIDANCE							PROJECT DESIGN PARAMETERS						LOCATION AND GEOMETRY			ASSOCIATED STRUCTURES & EQUIPMENT			
			C.1 Lead/Discipline Scope of Work	C.2 Project Codes and Standards	C.3 Topographical Surveys & Mapping	C.4 Project Site Assessment	C.5 Environmental & Regulatory Consid.	C.6 Value Analysis	C.7 Construction Input	D.1 Capacity	D.2 Design for Safety & Hazards	D.3 Civil and Structural	D.4 Mechanical and Equipment	D.5 Electrical and Controls	D.6 Operations and Maintenance	E.1 Schematic Layouts	E.2 Alignment and Cross-Section	E.3 Control Access	F.1 Support Structures	F.2 Hydraulic Structures	F.3 Miscellaneous Elements	F.4 Equipment List
NATURAL WORLD	NW1.1	Preserve Sites of High Ecological Value	X	X	X	X	X					X				X	X	X				
	NW1.2	Provide Wetland & Surface Water Buffers	X	X	X	X	X					X				X	X	X				
	NW1.3	Preserve Prime Farmland	X	X	X	X	X					X				X	X	X				
	NW1.4	Preserve Undeveloped Land	X	X	X	X	X					X				X	X	X				
	NW2.1	Reclaim Brownfields	X		X	X	X	X	X	X		X				X	X	X				
	NW2.2	Manage Stormwater	X	X	X	X	X	X	X			X				X	X	X	X	X		
	NW2.3	Reduce Pesticide & Fertilizer Impacts	X	X			X	X			X	X										
	NW2.4	Protect Surface & Groundwater Quality	X	X		X	X				X	X								X		
	NW3.1	Enhance Functional Habitats	X	X	X	X	X					X				X	X	X				
	NW3.2	Enhance Wetland & Surface Water Funct.	X	X	X	X	X					X				X				X		
	NW3.3	Maintain Floodplain Functions	X	X	X	X	X					X				X				X		
	NW3.4	Control Invasive Species	X			X	X				X	X			X							
	NW3.5	Protect Soil Health	X	X	X	X	X				X	X										
CLIMATE AND RESILIENCE	CR1.1	Reduce Net Embodied Carbon	X	X			X	X	X		X	X	X	X	X							X
	CR1.2	Reduce Greenhouse Gas Emissions	X	X		X	X				X	X	X	X	X						X	X
	CR1.3	Reduce Air Pollutant Emissions	X	X		X	X				X	X	X	X	X						X	X
	CR2.1	Avoid Unsuitable Development	X		X	X	X				X	X				X	X					
	CR2.2	Assess Climate Change Vulnerability	X					X			X	X										
	CR2.3	Evaluate Risk and Resilience	X					X			X	X										
	CR2.4	Establish Resilience Goals and Strategies	X					X			X	X										
	CR2.5	Maximize Resilience	X					X			X	X										
	CR2.6	Improve Infrastructure Integration	X								X	X			X							

- ***NW1.3 Preserve Prime Farmland****:* protect any soil designated as prime farmland, unique farmland, or farmland of importance. This credit requires decisions under C.1-C.5, D.3, E.1, E.2, and E.3 of PDRI.

- ***NW1.4 Preserve Undeveloped Land:*** identify and protect undeveloped land by locating the project in a previously developed land. Decisions for this credit can be made under C.1-C.5, D.3, E.1, E.2, and E.3 of PDRI.

- ***NW2.1 Reclaim Brownfields:*** protect the land by locating the project on sites classified as brownfields or known to contain contamination. This credit requires decisions under C.1, C.3-C.7, D.1, D.3, and E.1-E.3 of PDRI.

- ***NW2.2 Manage Stormwater:*** this credit tries to minimize the impact of a project on stormwater runoff quantity, rate, and quality. Decisions for this credit can be made under C.1-C.7, D.3, E.1-E.3, F.1, and F.2 of PDRI.

- ***NW2.3 Reduce Pesticide & Fertilizer Impacts:*** this credit intends to minimize air pollution by reducing the quantity, toxicity, bioavailability, and persistence of pesticides and fertilizers. Decisions for this credit can be made under C.1, C.2, C.5, C.6, D.2, and D.3 of PDRI.

- ***NW2.4 Protect Surface & Groundwater Quality:*** protect and preserve water resources by avoiding contamination from pollutants and monitoring impacts during construction and operation. This credit needs decisions made under C.1, C.2, C.4, C.5, D.2, D.3, and F.2 of PDRI.

- ***NW3.1 Enhance Functional Habitats:*** this credit intends to preserve and improve the functionality of terrestrial habitats. Avoiding and minimizing impact over these habitats can be achieved through decisions under C.1-C.5, D.3, E.1, E.2, and E.3 of PDRI.

- ***NW3.2 Enhance Wetland & Surface Water Functions:*** this credit provides points for projects that preserve and restore the ecosystem function of water bodies and wetlands. Decisions can be made under all elements of the project strategy category and C.1-C.5, D.3, E.1, and F.2 of PDRI.

- ***NW3.3 Maintain Floodplain Functions:*** restrict the development in floodplains in order to preserve their natural functions. This requires decisions under C.1-C.5, D.3, E.1, and F.2 of PDRI.
- ***NW3.4 Control Invasive Species:*** this credit promotes the use of noninvasive species and recommends long-term management, control, and elimination plan for these species. This credit entails decisions under the scope definition elements C.1, C.4, C.5, D.2, D.3, and D.6.
- ***NW3.5 Protect Soil Health****:* protect and maintain the composition, structure, and function of site soils. This includes restoring 100% of areas disturbed during construction and planning for future maintenance. This requires decisions under C.1-C.5, D.2, and D.3 of PDRI.

The Envision™ rating system also provides a comprehensive project planning framework to help stakeholders pursue infrastructure projects in the 'right' way (ISI 2018). Integrating sustainability principles, including social and environmental aspects, can influence the entire project management process, i.e. the requirements of the project's final output (Silvius and Schipper 2014). Research findings during this phase demonstrate the adequate steps to include 59 sustainability criteria during twenty scope definition elements of the Basis of Design process.

III.2.2. Phase 2: Developing framework for Basis of Project Decision and Sustainability

This phase consisted of creating a matrix that illustrates the existing synergies between 59 Envision™ credits and 23 scope definition elements from the Basis of Project Decision (BPD) section of the PDRI-Infrastructure tool. The developed matrix is presented in Table 6, in which all appropriate decisions during the PDRI are connected to the sustainability credits through an "X" label. Three credits from the Envision™ Climate and Resilience (CR) category were selected to provide an example of the in-depth analysis. These credits are the most important ones inside the CR category, and the logic used to link them with the PDRI decisions is explained below.

- ***CR2.1 Avoid Unsuitable Development:*** The intent of this credit is to minimize construction on hazardous sites to avoid site-related risks (ISI 2018). This credit needs to be considered during A.1 Need & Purpose Documentation since this BPD element aids in identifying and selecting alternatives, i.e. a proper location of the project. The CR2.1 credit also requires decisions under A.2 Investment Studies since it may need investment in preliminary surveys, such as geographic information systems (GIS), satellite imaging, site, and environmental conditions, safety and social studies, and more. The B.1 Design Philosophy element should also consider this credit since it includes issues such as environmental sustainability, safety improvement requirements, hazard mitigation strategies, and compliance with applicable jurisdictional requirements. All these issues may need to be considered while deciding the project site to avoid unsuitable development. D.1 Project Objectives Statement was correlated to this credit because it considers any limitation placed on the project and multiple performance objectives, i.e. sustainability and security. Element D.5 Site Characteristics was also considered to be correlated to this credit. After all, it aids in considering any site-related characteristics including uncertainty and investigation of existing conditions. D.8 Lead/Discipline Scope of Work was correlated to all sustainability credits because it includes a complete description of the project, including background information and sequencing of work. Lastly E.1 Value Engineering and E.2 Design Simplification were connected to CR2.1 because they assess a project's overall effectiveness and may help in identifying alternatives without compromising safety, function, and security.

- ***CR2.3 Evaluate Risk and Resilience:*** The intent of this credit is to identify risk and resilience-related risks and hazards (ISI 2018). This credit helps to identify vulnerabilities of the infrastructure's critical functions, which is considered during the A.1 Need and Purpose Documentation of the BPD. The risk evaluations may be done through collaborative work between all stakeholders including the community affected by the project (A.3 Key Team Member Coordination and A.4 Public Involvement). Additionally, the project needs to be designed following sustainability and safety guidelines, which are included in the B.1 Design Philosophy of BPD. And, if there are possibilities of expansion in the project, risk and resilience evaluation should also be considered for those future stages (B.4 Future Expansion Considerations). Similarly, all risk assessment activities need to be included in the project's cost and schedule estimates (C.1 Funding, C.2 Preliminary Project Schedule), and in the project objectives (D.1 Project Objectives statements). Besides, while identifying threats and hazards, the project team must consider all possible compliance with national, regional, and local requirements, including design and control standards (D.3 Evaluation of Compliance Requirements). Finally, as with all other sustainability criteria, the evaluation of risk and resilience must be included in the project's scope of work (D.8 Lead/Discipline Scope of Work)

- ***CR2.5 Maximize Resilience:*** The objective of this credit is to maximize the project's durability to increase its ability to withstand hazards (ISI 2018). In order to do so, the project team needs to establish resiliency goals and strategies, as well as to define the need of the project which may include site visits and stakeholders and public input (A.1 Need and Purpose Documentation, A.3 Key Team Member Coordination, and A.4 Public Involvement). In some cases implementing resiliency strategies may result in additional costs and time, which is why the CR2.5 credit should be considered during investment analyses, and cost and schedule estimates (A.2 Investment Studies, C.1 Funding and Programming, and C.2 Preliminary Project Schedule). Resiliency is critical to a project's entire lifecycle, thus, it must be considered during design, operation, and maintenance phases as well as possible future activities (B.1 Design, B.2 Operating, and B.3 Maintenance Philosophies, and B.4 Future Expansion). Additionally, all resiliency goals and approaches need to be included in the project objectives and scope of work (D.1 Project Objectives statements, and D.8 Lead/Discipline Scope of Work) as well as comply with national, regional, and local standards and codes (D.3 Evaluation of Compliance Requirements). Finally, when considering possible resiliency strategies, the project team may identify and document activities that optimize the project's performance (E.2 Design Simplification)

Table 6. Envision-BPD Framework

Envision™ Credits		PDRI Basis of Project Decision	PROJECT STRATEGY				OWNER / OPERATOR PHILOSOPHIES				PROJECT FUNDING AND TIMING			PROJECT REQUIREMENTS								VALUE ANALYSIS			
			A.1 Need & Purpose Documentation	A.2 Investment Studies & Alt. Assessm.	A.3 Key Team Member Coordination	A.4 Public Involvement	B.1 Design Philosophy	B.2 Operating Philosophy	B.3 Maintenance Philosophy	B.4 Future Expansion & Alteration Consid.	C.1 Funding & Programming	C.2 Preliminary Project Schedule	C.3 Contingencies	D.1 Project Objectives Statements	D.2 Functional Classification & Use	D.3 Evaluation of Compliance Req.	D.4 Existing Environmental Conditions	D.5 Site Characteristics Available vs. Req.	D.6 Dismantling & Demolition Req.	D.7 Determination of Utility Impacts	D.8 Lead/Discipline Scope of Work	E.1 Value Engineering Procedures	E.2 Design Simplification	E.3 Material Alternatives Considered	E.4 Constructability Procedures
QUALITY OF LIFE	QL1.1	Improve Community Quality of Life	X	X	X	X	X	X	X	X	X		X	X					X		X				
	QL1.2	Enhance Public Health and Safety	X			X	X	X	X	X				X					X		X				
	QL1.3	Improve Construction Safety	X		X	X							X	X		X			X		X				
	QL1.4	Minimize Noise and Vibration	X	X		X	X	X			X	X		X		X			X		X				
	QL1.5	Minimize Light Pollution	X	X		X	X	X			X	X		X		X			X	X	X				
	QL1.6	Minimize Construction Impacts	X	X		X	X	X			X	X		X		X			X	X	X	X	X	X	X
	QL2.1	Improve Community Mobility	X		X	X	X			X			X	X							X				
	QL2.2	Encourage Sustainable Transportation	X	X	X	X	X	X	X	X	X		X	X							X				
	QL2.3	Improve Access & Wayfinding	X		X		X			X			X	X			X				X				
	QL3.1	Advance Equity and Social Justice	X		X	X					X		X	X							X				
	QL3.2	Preserve Historic and Cultural Resources	X	X		X	X	X	X	X	X			X			X				X				
	QL3.3	Enhance Views and Local Character	X			X					X			X			X	X			X				
	QL3.4	Enhance Public Space & Amenities	X			X					X			X				X			X				
LEADERSHIP	LD1.1	Provide Effective Leadership & Commitment	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	LD1.2	Foster Collaboration and Teamwork	X	X	X						X			X					X		X	X			
	LD1.3	Provide for Stakeholder Involvement	X	X	X	X					X			X							X				
	LD1.4	Pursue By-Product Synergy	X	X			X				X	X	X	X							X	X	X	X	X
	LD2.1	Establish a Sustainability Management Plan	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	LD2.2	Plan for Sustainable Communities	X			X	X			X	X			X					X		X				
	LD2.3	Plan for Long-Term Monitoring & Mainten.	X		X				X	X	X		X	X					X		X	X			X
	LD2.4	Plan for End-of-Life	X		X				X	X	X			X					X		X				
	LD3.1	Stimulate Economic Prosperity & Develop.	X	X			X			X	X	X	X	X							X				
	LD3.2	Develop Local Skills & Capabilities	X	X	X	X								X							X				
	LD3.3	Conduct a Life-Cycle Economic Evaluation	X	X			X	X	X	X	X	X	X	X							X				
RESOURCE ALLOCATION	RA1.1	Support Sustainable Procurement Practices	X		X		X	X	X	X				X	X	X	X		X		X	X	X	X	X
	RA1.2	Use Recycled Materials	X			X	X	X			X	X	X	X		X		X			X	X	X	X	
	RA1.3	Reduce Operational Waste	X	X				X			X			X					X		X	X			
	RA1.4	Reduce Construction Waste	X	X				X	X		X			X							X	X			
	RA1.5	Balance Earthwork On Site	X											X		X	X	X			X	X	X		X
	RA2.1	Reduce Operational Energy Consumption	X	X				X			X			X					X	X	X		X		X
	RA2.2	Reduce Construction Energy Consumption	X	X			X	X			X			X						X	X		X		X
	RA2.3	Use Renewable Energy	X	X			X	X	X		X	X	X	X		X	X	X		X	X	X	X	X	X
	RA2.4	Commission & Monitor Energy Systems	X	X	X		X	X	X					X		X	X	X	X	X	X				
	RA3.1	Preserve Water Resources	X			X								X		X	X				X				
	RA3.2	Reduce Operational Water Consumption	X	X				X			X			X						X	X		X		X
	RA3.3	Reduce Construction Water Consumption	X	X			X	X			X			X						X	X		X		X
	RA3.4	Monitor Water Systems	X	X	X		X	X	X				X	X			X	X			X				

Table 6. Envision-BPD Framework (Continued)

Envision™ Credits		PDRI Basis of Project Decision	PROJECT STRATEGY				OWNER / OPERATOR PHILOSOPHIES				PROJECT FUNDING AND TIMING			PROJECT REQUIREMENTS								VALUE ANALYSIS			
			A.1 Need & Purpose Documentation	A.2 Investment Studies & Alt. Assessm.	A.3 Key Team Member Coordination	A.4 Public Involvement	B.1 Design Philosophy	B.2 Operating Philosophy	B.3 Maintenance Philosophy	B.4 Future Expansion & Alteration Consid.	C.1 Funding & Programming	C.2 Preliminary Project Schedule	C.3 Contingencies	D.1 Project Objectives Statements	D.2 Functional Classification & Use	D.3 Evaluation of Compliance Req.	D.4 Existing Environmental Conditions	D.5 Site Characteristics Available vs. Req.	D.6 Dismantling & Demolition Req.	D.7 Determination of Utility Impacts	D.8 Lead/Discipline Scope of Work	E.1 Value Engineering Procedures	E.2 Design Simplification	E.3 Material Alternatives Considered	E.4 Constructability Procedures
NATURAL WORLD	NW1.1	Preserve Sites of High Ecological Value	X	X		X	X	X			X		X	X			X	X			X				
	NW1.2	Provide Wetland & Surface Water Buffers	X	X		X	X	X						X			X	X			X				
	NW1.3	Preserve Prime Farmland	X	X		X	X	X						X			X	X			X				
	NW1.4	Preserve Undeveloped Land	X	X		X	X	X		X				X			X	X			X				
	NW2.1	Reclaim Brownfields	X										X	X			X				X				
	NW2.2	Manage Stormwater	X	X		X	X	X	X	X	X			X	X	X	X	X	X		X	X			X
	NW2.3	Reduce Pesticide & Fertilizer Impacts	X			X	X							X		X	X				X		X		X
	NW2.4	Protect Surface & Groundwater Quality	X			X		X						X		X	X				X				
	NW3.1	Enhance Functional Habitats	X	X		X	X				X		X	X			X				X				
	NW3.2	Enhance Wetland & Surface Water Funct.	X	X	X	X	X							X		X	X				X	X			
	NW3.3	Maintain Floodplain Functions	X	X			X	X	X	X				X			X				X	X			
	NW3.4	Control Invasive Species	X	X		X	X	X	X		X	X	X	X		X	X				X	X			X
	NW3.5	Protect Soil Health	X	X		X	X	X	X		X			X			X				X				
CLIMATE AND RESILIENCE	CR1.1	Reduce Net Embodied Carbon	X	X			X	X	X	X	X			X			X			X	X	X		X	
	CR1.2	Reduce Greenhouse Gas Emissions	X	X			X	X			X			X		X	X		X	X	X	X		X	
	CR1.3	Reduce Air Pollutant Emissions	X	X		X	X							X		X	X			X	X	X		X	
	CR2.1	Avoid Unsuitable Development	X	X			X							X				X			X	X	X		
	CR2.2	Assess Climate Change Vulnerability	X	X			X							X		X	X				X				
	CR2.3	Evaluate Risk and Resilience	X		X	X	X			X	X	X		X		X					X				
	CR2.4	Establish Resilience Goals and Strategies	X	X	X	X	X							X		X					X				
	CR2.5	Maximize Resilience	X	X	X	X	X	X	X	X	X	X		X		X					X		X		
	CR2.6	Improve Infrastructure Integration	X	X			X				X			X				X	X		X	X			X

According to the findings of this phase, the boxes marked with an "X" in Table 6 represent the existing correlations between each sustainability credit and each PDRI element from the Basis of Project Decision section. These decisions considered the ISI Envision Manual (2018) and the CII PDRI-Infrastructure tool (Bingham and Gibson Jr. 2010) and have been confirmed by the results obtained from 45 Envision™ case-study projects. The developed matrix allows stakeholders to easily identify during which phases of Front-End Planning, the corresponding sustainability credits may be pursued.

Research findings of Shivakumar et al. (2014) and Weerasinghe et al. (2007) as well as results obtained from this study demonstrate that implementing sustainability criteria at the FEP phases of a project can reduce risks and uncertainties while increasing the possibilities of a successful and resilient project. Additionally, previous investigations have indicated that sustainable projects may focus more on proper FEP than conventional projects, resulting in better cost performance and reduced change orders (Kang et al. 2013). Thus, the additional efforts that sustainable projects implicate can be better justified since they can result in better cost performance than traditional projects. To this end, the frameworks developed in this chapter aid in the FEP process of sustainable infrastructure projects for all stakeholders.

III.2.3. Phase 3: Multiple case-study analysis

As a validation approach to the frameworks presented in this chapter, the author conducted surveys to 109 industry professionals with more than 10 years of experience in an infrastructure project. These stakeholders provided information about 45 Envision™ verified projects that included the approximate value of the Envision™ project, the rate of success, the financial and change management performance, the strengths and weaknesses of the Envision™ rating system, the challenges presented during the certification, and in which stages of the project life cycle they applied Envision™. The 45 projects were used as case-studies during this phase's analysis since they represent more than 60% of the current number of projects that have received an Envision™ certification in the United States.

All surveyed professionals agreed that the sustainability certification process serves as a project planning outline and has improved the overall performance of their projects. The respondents mentioned that, although Envision™ can be applied throughout the entire project life cycle, including the end-of-useful-life activities, sustainability begins at the early stages of planning and design. This connects Envision™ with the processes of Front-End Planning (FEP) on infrastructure projects. Respondents also agreed that the PDRI tools can support a better and smoother process towards sustainability certification.

The survey answers resulted in qualitative and quantitative data, which was later analyzed and evaluated to support Table 5 and Table 6. For ease of understanding the author divided the information from the matrices into separate sections, according to Envision™ categories, where the discussions from the surveys were allocated to show how the Envision™ rating system and the PDRI tools work together. Table 7 summarizes some of the FEP processes that the respondents followed during the sustainability certification.

Based on the survey responses, the majority of the case-study projects would have benefited from a standardized FEP process or tool during the sustainability certification, i.e. a similar framework to the ones developed in this research. The activities they pursued throughout the project to accomplish the sustainability credits were strongly related to FEP, as can be seen from the examples given in Table 7. Many infrastructure projects in which the stakeholders contributed seldom integrated sustainability in an early manner, i.e. during FEP. Consequently, there were not only uncertainty and barriers to its successful operation but also unexpected costs to address environmental implications after the design phase had been initiated. All respondents agreed that to pursue an Envision™ sustainability certification, all credits and procedures should be analyzed prior to project initiation, i.e. during FEP. This early design work includes defining the owner's requirements and including them in the overall project strategy (Weerasinghe et al. 2007). It involves more than basic design, like the selection of the location, the right materials and systems, innovative technology, risk management, and so forth. This way, the case-study survey responses and the presented Table 7 serve as a supporting document to the frameworks developed in Table 5 and Table 6.

Table 7. Case-study-based results of Envision™ during FEP

ENVISION CATEGORIES	FRONT-END PLANNING PROCESS
QUALITY OF LIFE (QL)	• Community demographic studies. • Overall planning and basic design in resource area • Defining and selecting project alternatives • Improve economies and enhance livability throughout the region • Alternative Technical Concept (ATC) to pursue better improvement in the wellbeing of the community • Innovative construction methodologies to protect and improve public health and safety • Implementation of energy efficient lightning • Analysis of types of conveyance, and products to be conveyed • Cultural resource surveys (historical preservation, archeological sites)
LEADERSHIP (LD)	• Project fund and budget details • Effective collaboration between owner and project team • Planning for sustainability • Stakeholder identification and management • Commissioning and decommissioning strategies • Stablish controlling legal terms and conditions • Profitability analyses • Sustainability objectives; sustainable certification process
RESOURCE ALLOCATION (RA)	• Zoning and ecological design ideas • Value engineering procedures • Site surveying • Life cycle cost studies • Technological needs assessment • Operation requirements • Maximize the use of durable materials with recycle content • Sustainability objectives; sustainable certification process • Hazardous materials studies

Table 7. Case-study-based results of Envision™ during FEP (Continued)

ENVISION CATEGORIES	FRONT-END PLANNING PROCESS
NATURAL WORLD (NW)	• Ecological design ideas • Running water and sewage design • Water conservancy ideas • Contamination Management Plans and Spill prevention • Remediation in areas of contamination within the project's right-of-way • Selection of non-invasive species • Environmental assessment and conservation programs • Analysis of environmental and mitigation costs • Sustainability objectives; sustainable certification process • Natural resource surveys
CLIMATE AND RESILIENCE (CR)	• Water treatment requirements • Analysis of site conditions • Conform plans to necessary standards and codes • Environmental assessment • Site Surveys and Visits • Project management plan to mitigate risks • Application of innovative chemical materials to protect air quality during construction • Interface with other future infrastructure projects • Analysis of environmental and mitigation costs • Sustainability objectives; sustainable certification process

In addition, some interesting and valuable responses indicated that the entire team should have sustainability knowledge, not only top management. It was specifically mentioned that the highest rank director needs to demand sustainability to all teams. This presents an additional challenge: teaching sustainability to all stakeholders. One gap in the knowledge of these important topics and a possible solution were included in Chapter II.

III.3. Chapter III Conclusions

This chapter explained how sustainable infrastructure criteria work hand in hand with scope definition elements during the Front-End Planning process, specifically during the Basis of Design (BOD) and the Basis of Project Decision (BPD) phases. Two matrix frameworks were created to correlate 59 sustainability credits for infrastructure projects to a total of 43 scope definition elements. The sustainability credits, included in the

Envision™ rating system, were divided into five categories: (1) Quality of Life (QL), (2) Leadership (LD), (3) Resource Allocation (RA), (4) Natural World (NW), and (5) Climate and Resilience (CR). The scope definition elements were selected from the highest-weighted categories from each of the PDRI tools for infrastructure projects (PDRI-Infrastructure and PDRI-Small Infrastructure). These categories being: Section I: Basis of Project Decision (BPD) from the PDRI-Infrastructure, and Section II: Basis of Design (BOD) from the PDRI-Small Infrastructure tool. The BPD section involves 23 elements divided into five categories: (1) project strategy, (2) owner/operator philosophies, (3) project funding and timing, (4) project requirements, and (5) value analysis. While the BOD section has 20 scope definition elements divided into: (1) design guidance, (2) project design parameters, (3) location and geometry, and (4) associated structures and equipment.

The framework developed in this chapter help stakeholders to smoothly transition from pre-planning to design and construction while considering the entire Triple Bottom Line of sustainability in infrastructure projects. Stakeholders can easily identify from Table 5 and Table 6 when, during FEP, each sustainability criteria should be considered. Thus, the developed framework may reduce uncertainty and risks while improving resiliency and overall sustainability; it allows project stakeholders to set suitable schedule and costs estimates, as well as procurement requirements.

According to the findings of this study, the scope definition elements from the BPD and the BOD phases are very correlated with all presented sustainability credits. Sustainable infrastructure goals like the improvement of the community's life quality, the engagement of stakeholders, and the pursuit of the best project solution can be accomplished by properly defining the scope of the project at FEP phases. The existing synergies between FEP and SI have been demonstrated and supported through case-study analysis. 109 stakeholders were surveyed to support the developed frameworks by investigating the sustainability and planning process of 45 case-study projects. All respondents indicated that applying sustainability to their infrastructure projects has improved their overall performance, including reduced costs and shorter schedules. They agreed that the sustainability certification process serves as a project planning outline, but that following an FEP tool (i.e. the PDRI) would have been much more helpful. The scope definition elements presented in this chapter, together with all sustainability criteria, can aid project managers in determining adequate estimates and requirements. In addition, the matrices advise project stakeholders to focus more on elements that have a higher impact on the performance of a project and support a detailed scope definition by reducing uncertainty and risks associated with the project. Overall, the frameworks presented in this chapter form the foundation of a sustainable FEP tool for infrastructure projects. This research can be considered an ongoing effort that will expand through the growing need for effective and resilient approaches in the AEC industry.

CHAPTER IV

IV.1. A Unified Tool to Foster Front-End Planning and Sustainability in Infrastructure Projects

Climate change and waste management are two environmental issues that pose a growing challenge to the construction industry and are threatening the well-being of life on earth (Pradhananga and Elzomor 2020). Infrastructure projects play a critical role in the built environment, but these projects also tend to reduce the ability of the natural environment (i.e., pervious soils), its habitats, and species to adapt to climate change. Additionally, these projects face unique planning challenges such as right-of-way (ROW) acquisitions or adjustments, underground works, and more interface with the public and the environment. Low awareness of a project's societal and environmental impacts as well as a lack of standardized procedures to quantify these impacts are often roadblocks to achieving sustainability (Weerasinghe et al. 2007). Therefore, there is a growing need for innovative methods that can be utilized to not only achieve sustainability goals but also reduce schedule delays and cost overruns in infrastructure projects. To this end, Chapter IV is intended to downsize the previous Envision-PDRI frameworks, in order to make one new matrix that is handier and useful to the industry.

IV.2. Methodology

This chapter aims to investigate existing synergies between six key elements from the PDRI tools for infrastructure projects and twenty Envision™ credits to develop a reliable matrix that provides correlation and strategies to enhance project performance. In order to meet this goal, 109 stakeholders from more than 45 Envision™ certified projects were surveyed, which represents more than 60% of the current Envision™ certified projects in the U.S. The survey targeted people who actively work in the construction industry, but mostly those who have been involved in an infrastructure project. This chapter addressed research Hypothesis #1 and Hypothesis #2 by developing a reliable matrix that provides correlations and strategies to enhance project performance and sustainability, as well as identifying how a project's success can be enhanced when integrating Envision™ during FEP. Figure 13 summarizes the methodology of Chapter IV.

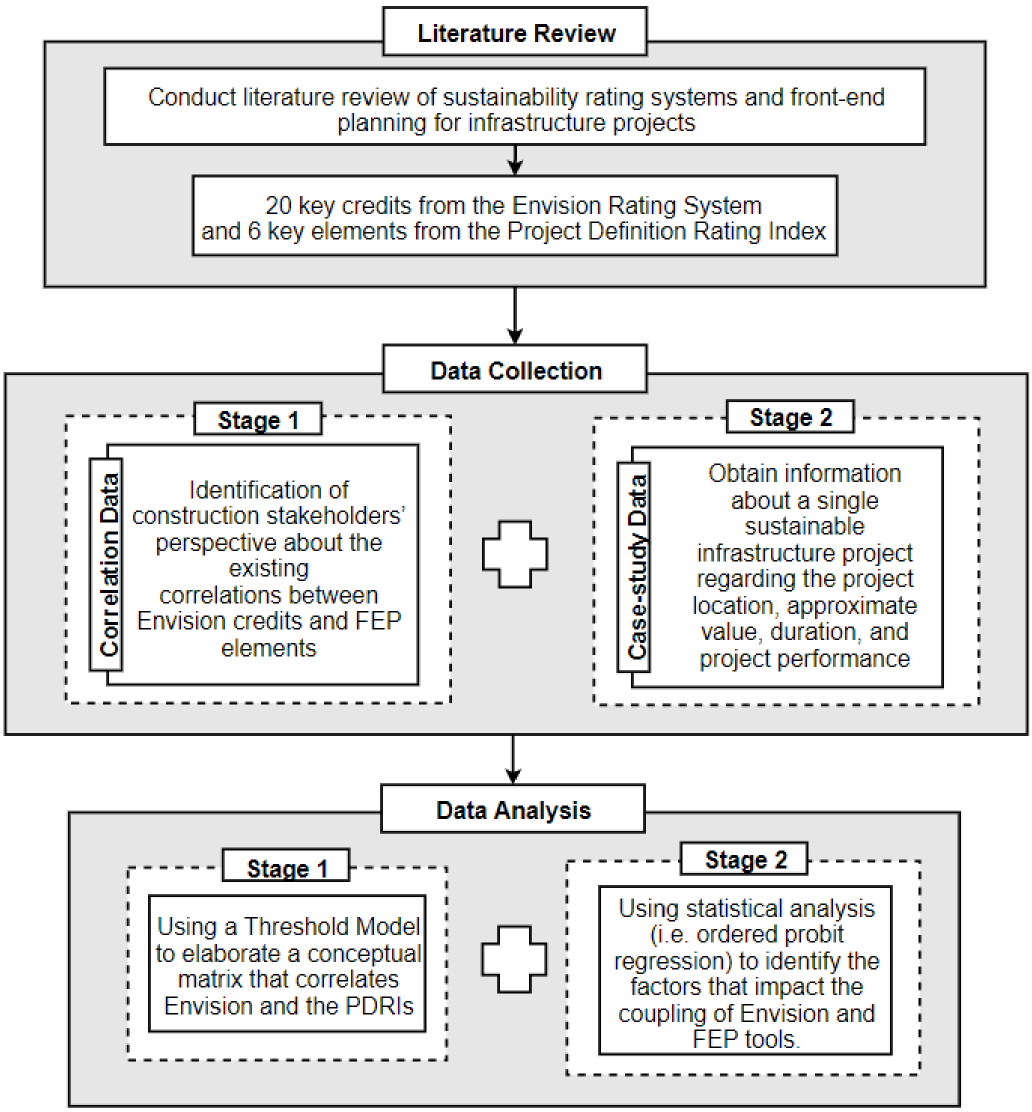

Figure 13. Chapter IV overview

The survey developed for this research was divided into three sections: (1) a correlation section focused on the identification of construction stakeholders' perspective about the existing synergies between Envision™ credits and FEP elements; (2) a case study section that entails information about a single infrastructure project that had included any sustainability criteria (i.e. location, approximate value, duration, and project performance) and (3) a socio-demographic section to learn about background and work experience of construction stakeholders.

The analysis and results were divided into two sections for the correlation analysis and the case study analysis. The results obtained from the correlation section were analyzed through a threshold model, where the Median of the answers distinguished the range of values that were considered for the development of a conceptual matrix. This matrix contains the twenty most important credits on the Envision™ rating system and six key categories of the PDRI for large and small infrastructure, as determined by Elzomor et al. (2018). This develops a precise and scaled-down framework that will help project stakeholders identify the strengths and weaknesses of a project before pursuing it. The conceptual matrix approach is partially based on the research finding of Weerasinghe et al. (2007), who developed a LEED-PDRI matrix. The authors highlighted that the matrix provides a logical and reliable framework that support team members in planning, assessing risks, and managing sustainable projects. This research intent is to define a similar but smaller matrix framework that connects the Envision™ rating system and the PDRI tools for infrastructure projects. The conceptual matrix only includes the twenty credits from the Envision™ rating system with the highest point value in their respective categories as shown in Figure 14.

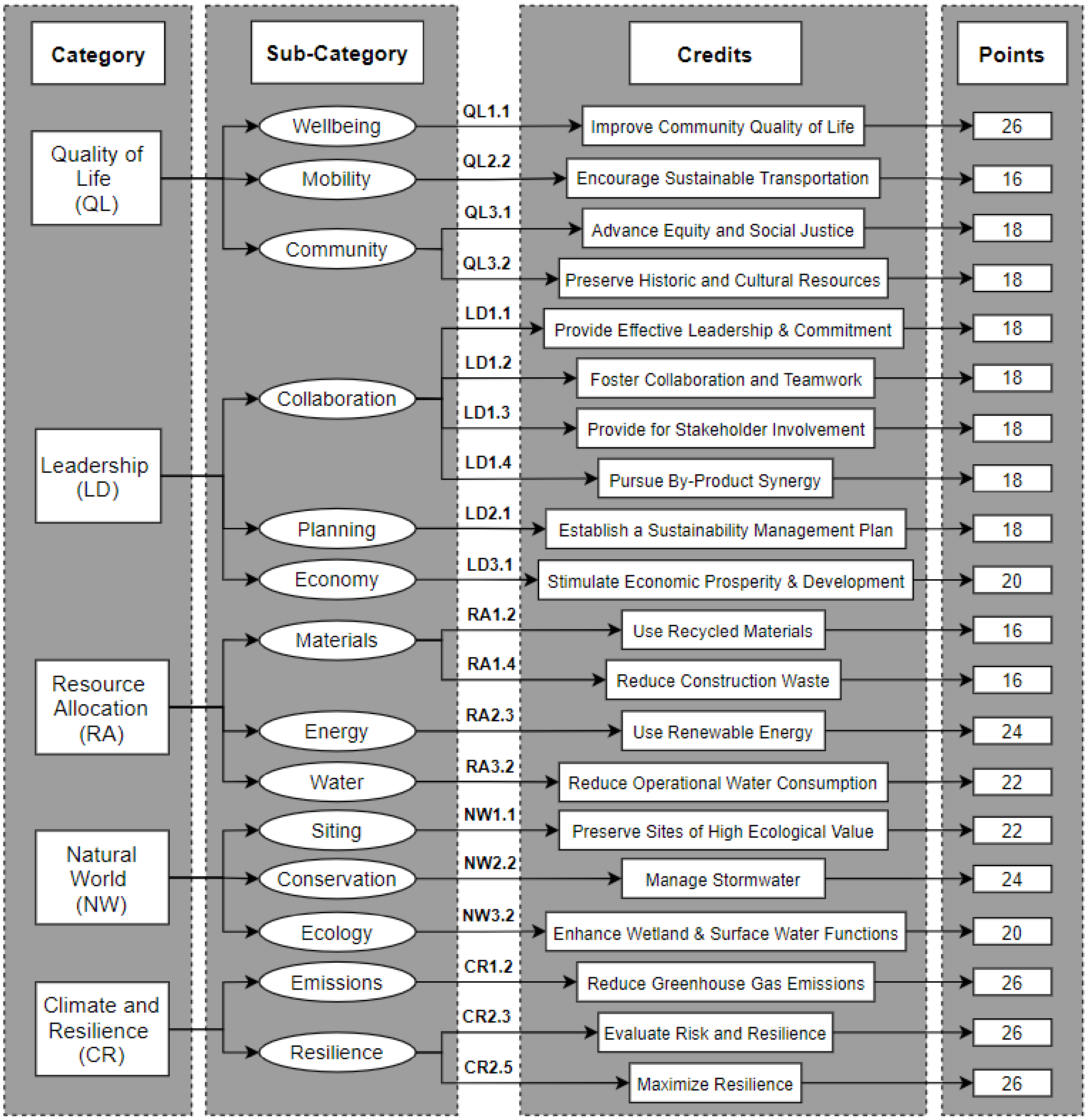

Figure 14. Envision™ credits considered in this study

Similarly, only some categories from the PDRI tools for infrastructure projects were considered. Section I: Basis of Project Decision from PDRI-Large Infrastructure was carefully chosen because it is the highest weighted section of PDRI-Large Infrastructure, representing 43.7% of the 1000 points. Thus, the elements that are included in this section are more likely to have an impact on the cost and schedule of a project's lifecycle

(Bingham and Gibson Jr. 2010). The Basis of Project Decision section includes helpful information to understand the project objectives. Similarly, Section II: Basis of Design was selected from PDRI-Small Infrastructure; this section evaluates processes and technical information elements for a full understanding of the engineering/design requirements necessary for the project. This section has been particularly chosen because it accounts for 47% of the 1000 points of PDRI-Small Infrastructure, which was confirmed by Elzomor et al. (2017). The choice of Section I and Section II for PDRI-Large Infrastructure and PDRI-Small Infrastructure respectively aligns with the notion that large infrastructure projects often require a robust decision-making effort to define the project scope and location (included in Section I) while less complex or "small" infrastructure projects may already have these items defined prior to FEP (Elzomor et al. 2017).

Figure 15 shows the categories selected from both PDRIs.

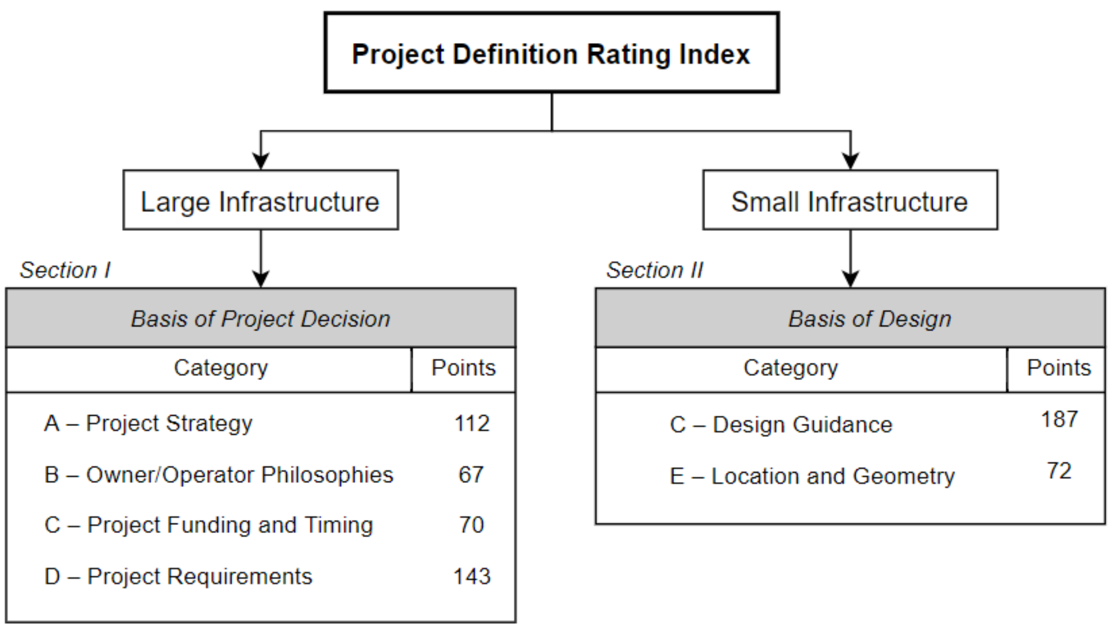

Figure 15. PDRI categories considered in this study.

To design the survey and the conceptual matrix, the authors excluded categories E-Value Analysis from Section I, and D – Project Design Parameters and F –Associated Structures & Equipment from Section II. This study incorporated only those elements that were considered important elements of PDRI based on Elzomor et al. (2018) findings identified through a survey of owners and contractors. The authors indicated that the aforementioned Categories D, E, and F are either inessential or related to all elements in Section I: Basis of Project Decision, due to which these categories were exempted from the study.

The research utilized an ordered probit regression model to analyze the case study survey. This analysis is fit for the generalization of cases of more than two outcomes of an ordinal dependent variable (a variable with potential values such as poor, fair, good, excellent). Therefore, since an ordered logit model estimates the probability of the dependent variable to be only one, the ordered probit regression model was the best fit for this study. This analysis is conducted so the researchers can identify which independent variable has a statistically significant effect on the dependent variable, as well as to determine how well the model predicts it. For this model, the dependent variable was defined as Expected Success of a Sustainable Infrastructure Project while the independent variables are (1) Awareness of Envision™, (2) Value of infrastructure project in US$, (3) Duration of Project Completion, (4) Financial Performance, and (5) Change Management Performance. The ordinal probit regression model utilizes these parameters through the following equation:

$$y_i^{*} = X_i \beta + \varepsilon \qquad (2)$$

Where y_i^* is a latent variable measuring the rate of success of an infrastructure project according to the ith participant; X_i is a (k x 1) vector of observed nonrandom explanatory variables; β is a (k x 1) vector of unknown parameters; and the error factor (ε) that captures the reality that the expected success is not perfectly predicted by the regression equation. Therefore, the Expected Success of a Sustainable Infrastructure Project, y_i is determined from the model as follows:

$$y_i = \begin{cases} 1\ if\ -\infty \le y_i^* \le \mu_1\ (Not\ successful) \\ 2\ if\ \mu_1 \le y_i^* \le \mu_2\ (Somewhat\ successful) \\ 3\ if\ \mu_2 \le y_i^* \le \mu_3\ (Successful) \\ 4\ if\ \mu_3 \le y_i^* \le \mu_4\ (Very\ Successful) \\ 5\ if\ \mu_4 \le y_i^* \le \mu_5\ (Extremely\ successful) \end{cases} \quad (3)$$

In equation 3, the partial change in y^* with respect to X_i is β units. This implies that for a unit change in X_i, y^* is expected to change by β units, holding all variables constant. Furthermore, the significance test that validates the ordered probit regression analysis uses the t-score to describe how the mean of the data sample with a certain number of observations (n = 109 in the case of this study) is expected to behave. On the other hand, the P-value indicates the confidence level, in terms of correlation, of independent variables to the dependent variable. The confidence interval in the analysis is assumed to be 90% for this study and the maximum desired P-value is set to 0.1.

IV.3. Results - Envision-FEP stakeholders' matrix

This section presents the results of the analyses and developed (1) a correlation matrix that facilitates the integration of sustainability decisions (the Envision™ rating system credits) during the scope definition of infrastructure projects (PDRI-small and large infrastructure tools); and (2) a regression model consisting of the factors that influence the success of sustainable infrastructure projects when coupling FEP and sustainability criteria. The respondents' demographic background is illustrated in Figure 16. It can be inferred that the entire population on the survey has a bachelor's degree or higher, and most of the respondents have working experience in infrastructure projects (87%). Moreover, 70 out of the 109 professionals that participated in the survey have over 10 years of experience, thus, their input is considered valuable to the study.

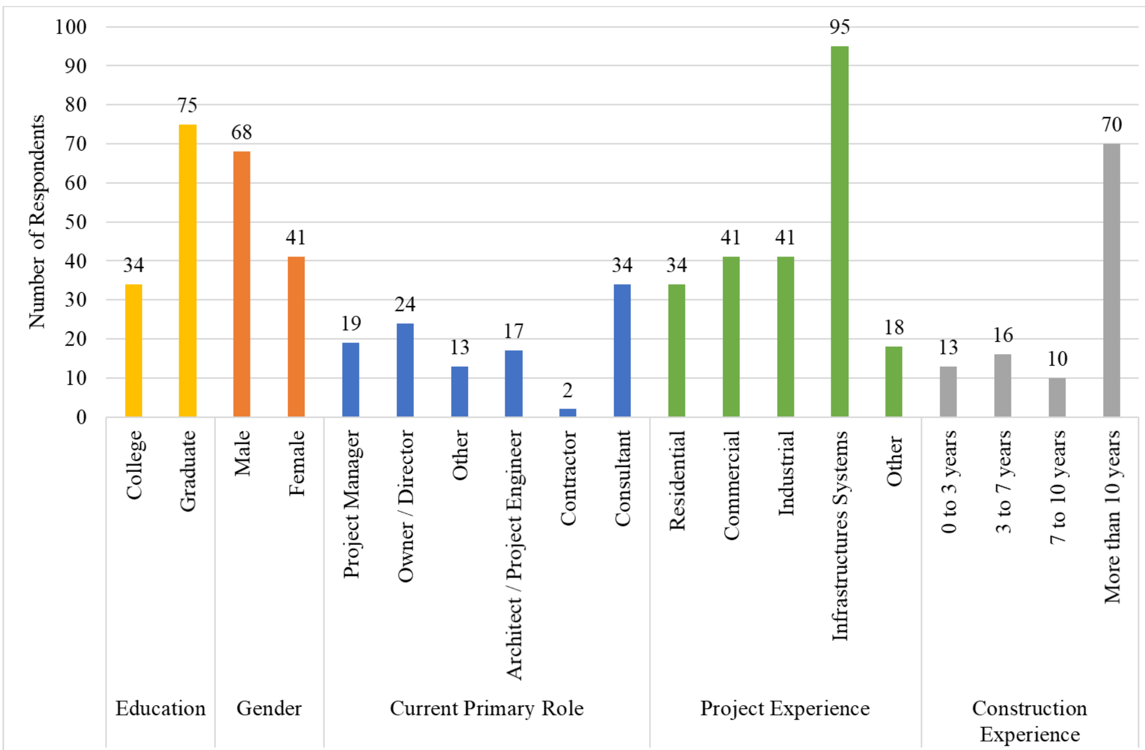

Figure 16. Respondents' socio-demographic background information (n=109)

IV.3.1. Envision-PDRI stakeholders' framework

The survey created for this study included questions that were designed to connect each previously selected PDRI element to its most relevant Envision™ credit. 109 respondents reported their opinion about the correlation between these elements. These answers allowed the author to successfully develop the matrix presented in Table 8. The boxes marked with an ‘X’ represent the Envision™ related decisions corresponding to each of the stages from the PDRI tools for infrastructure projects. The results of the survey related to correlations obtained in Table 8 can be interpreted as follows:

a) The project strategy is the first stage in a project that identifies the project's purpose, need, stakeholders, and activities. In this phase the public involvement is critical, thus it is important to include all credits from the Quality of Life (QL) category of Envision™. Since project objectives are formed during this stage, stakeholders need to be appropriately represented and there should be effective communication within the entire team; additionally, stakeholders should consider all business requirements including sustainability considerations (Elzomor et al. 2017). This aligns with the concepts of the Leadership (LD), Natural World (NW), and Climate and Resilience (CR) credits of Envision™.

b) The owner/operator philosophies define how is the project going to achieve the overall performance requirements (i.e., design, operations, maintenance goals). All Envision™ credits entail decisions under this scope definition strategy. However, credit LD1.4: Pursue By-Product Synergy wasn’t considered as important to this phase by the survey respondents. This may be due to a lack of understanding about value engineering processes.

c) Project funding and timing is the stage of the project where funding sources are identified, budgeted, and documented (i.e. cost estimates). Envision™ LD credits appear to be critical for the respondents during this stage, which can be a result of the need for an accurate project estimate. Additionally, the project funding stage was considered highly correlated to the materials, energy, water, and risk credits. One significant cause of this correlation is that all these credits can cause unexpected increases in the budget and schedule of an infrastructure project if not taken into account at early stages (Elzomor et al. 2017).

d) Project requirements address high-level requirements informing the basis of project design, such as project objectives statements, existing environmental conditions, site characteristics, functional classification, and use. The credits included in the Quality of Life (QL), Resource Allocation (RA), Natural World (NW), and Climate and Resilience (CR) categories, involve specific rules, procedures, and policies by regulating the use of resources and minimizing social impacts (Yu et al. 2018), which includes them in the project objectives and goals. Thus, these sustainability credits require scope decisions under the project requirements category.

e) Design guidance is the stage of the project where the elements required to support detailed design are identified. Some of these elements include defining the project's environmental and topographical conditions and assessing the project site. (Elzomor et al. 2017), which relate to credits under the RA, NW, and CR categories. Additionally, during the design guidance process, value analysis procedures are considered, as well as the necessary codes and standards according to the project; thus, credits that involve the community quality of life (QL) and stakeholder's alignment (LD) require decisions under the design guidance category.

f) The location and geometry of a project consider schematic layouts, alignments, cross-sections, and control of access information that are important to the design success of the project. Envision™ credits included in the Quality of Life (QL) and Natural World (NW) sections need scope definition elements under this category. The location of a sustainable project must be decided including potential sustainable transportation plans, and the preservation of high ecological value sites (i.e. prime farmlands, wetlands, national parks, etc.) (ISI 2018).

Table 8. Envision-PDRI stakeholders' framework

		PDRI Large and Small Infrastructure					
		Basis of Project Decision				Basis of Design	
		Project Strategy	Owner / Operator Philosophies	Project Funding and Timing	Project Requirements	Design Guidance	Location and Geometry
ENVISION CATEGORIES							
QUALITY OF LIFE							
QL1.1	Improve Community Quality of Life	X	X		X	X	
QL2.2	Encourage Sustainable Transportation	X	X		X		X
QL3.1	Advance Equity and Social Justice	X	X		X	X	X
QL3.2	Preserve Historic and Cultural Resources	X	X		X	X	X
LEADERSHIP							
LD1.1	Provide Effective Leadership & Commitment	X	X	X			
LD1.2	Foster Collaboration and Teamwork	X	X	X			
LD1.3	Provide for Stakeholder Involvement	X	X	X			
LD1.4	Pursue By-Product Synergy			X		X	
LD2.1	Establish a Sustainability Management Plan	X	X	X	X	X	
LD3.1	Stimulate Economic Prosperity & Development	X	X	X			
RESOURCE ALLOCATION							
RA1.2	Use Recycled Materials		X	X	X	X	
RA1.4	Reduce Construction Waste		X	X	X	X	
RA2.3	Use Renewable Energy	X	X	X	X	X	
RA3.2	Reduce Operational Water Consumption	X	X	X	X	X	
NATURAL WORLD							
NW1.1	Preserve Sites of High Ecological Value	X	X		X	X	X
NW2.2	Manage Stormwater	X	X		X	X	X
NW3.2	Enhance Wetland & Surface Water Functions	X	X		X	X	X
CLIMATE AND RESILIENCE							
CR1.2	Reduce Greenhouse Gas Emissions	X	X		X	X	
CR2.3	Evaluate Risk and Resilience	X	X	X	X	X	
CR2.5	Maximize Resilience	X	X	X	X	X	

The Envision™ rating system is not only a sustainability manual, but it also functions as a project planning framework to help stakeholders pursue the 'right' infrastructure project in the 'right' way (ISI 2018). Integrating sustainability principles, including social and environmental aspects, can influence the entire project management process, i.e. the requirements of the project's final output (Silvius and Schipper 2014). Previous research and results from this study demonstrate that implementing Envision™ at the early stages of a project (i.e. FEP) can reduce risks and uncertainties while increasing the possibilities of a successful and sustainable project (Shivakumar et al. 2014; Weerasinghe et al. 2007). Additionally, it has been indicated that a sustainable building project would usually emphasize more on accurate FEP than conventional projects, resulting in better cost performance and reduced change orders (Kang et al. 2013). Thus, the additional efforts that sustainable projects implicate can be better justified since they can result in better cost performance than traditional projects. To this end, the Envision™-PDRI framework developed in this study, aids in the pre-construction planning process of sustainable projects for all stakeholders.

IV.3.2. Expected success of sustainable infrastructure project

To identify the factors that impact the coupling of the sustainability rating system and FEP tools, an ordered probit model was developed. This analysis investigated the expected success of an infrastructure project that integrates sustainability criteria in its pre-planning process. The ordered probit method was selected since it provides an appropriate fit to the data obtained. Table 9 shows the estimated results of the impact that the variables have on the success of a sustainable infrastructure project, with a pseudo R^2 value of 0.2681. Although the R^2 seems small, it is different from zero, which indicates statistical significance in the regression model (Hu et al. 2006). The *P*-value of the respondents' awareness of sustainability procedures, the selected project value, duration, financial performance, and change management performance are 0.006, 0.094, 0.178, 0.000, and 0.006, respectively. Variable 3 (Duration of the project) has a *P*-value higher than 0.1 meaning that it is not statistically significant and does not support the hypothesis of the regression model. Since the P-value of the other significant variables is less than 0.1, it can be concluded that the hypothesis pertaining to the existence of the true relationship between the dependent variable and the independent variables mentioned before is correct. Thus, the data is statistically significant. In Table 9, μ_1, μ_2, μ_3, and μ_4 are the coefficients of the ordered probit model with the values 1.407, 2.084, 3.404, and 5.341 respectively. These values are the thresholds that reflect the predicted cumulative probabilities at covariate values of zero.

Table 9. Coefficients and P-Value from Ordered Probit Analysis

Variables	Coeff (β)	Std. Error	Z	P-Value
1. Indicator variable for respondents' awareness of sustainability procedures. *(1 if the respondent is aware, 0 otherwise)*	0.839	0.303	2.77	0.006
2. Indicator variable for the value of the selected project. *(1 if value in $US is higher than 10.000.000, 0 otherwise)*	0.545	0.325	1.68	0.094
3. Indicator variable for the duration of the selected project. *(1 if the duration is more than 18 months, 0 otherwise)*	-0.520	0.386	-1.35	0.178
4. Financial performance of the selected project. *(A higher number for better performance)*	0.655	0.142	4.60	0.000
5. Change management performance of the selected project. *(A higher number for reduced design change orders)*	0.392	0.143	2.73	0.006
μ_1	1.407	0.809		
μ_2	2.084	0.777		
μ_3	3.404	0.813		
μ_4	5.342	0.913		

All the coefficients of statistically significant factors in Table 9 have a positive correlation with the dependent variable in the regression model indicating that with the increase in the value of these factors, the rate of success of a sustainable infrastructure project is more likely to increase. The results related to the first variable (Awareness of sustainability processes) may be derived from the increased ability to integrate sustainability features from those stakeholders that understand the Envision™ process. Professionals that have achieved accreditation as Envision™ Sustainability Professionals (ENV SP) can use the Triple-Bottom Line concepts to improve the sustainability of their projects and their overall performance (Vandebergh et al. 2016). In the case of the second and fourth variables, the projects that are valued at more than US$ 10.000.000 with great financial performance, are more likely to achieve success by pursuing a sustainability certification. This may relate to the higher budget capacity that these projects have to invest in new techniques and tools and pursue a sustainability certification. Lastly, the results obtained for the fifth variable, regarding the change management performance of the project, may be caused by the increased ability to make changes effectively at the beginning of a sustainable infrastructure project planning. Applying sustainability procedures, like the Envision™ rating system, at the early stages of an infrastructure project (i.e. FEP phases) can significantly improve the change management performance of a project (ISI 2018). These relationships demonstrate that integrating sustainability criteria to a project can enhance its effectiveness, in terms of cost, schedule, change orders, and resiliency. Hence, the results obtained through the ordinal probit model align with the developed Envision-PDRI framework of this chapter.

IV.4. Chapter IV Conclusion

This chapter demonstrates how the Envision™ rating system aids in the scope definition process (PDRI) of infrastructure projects. Envision™ can also be considered a Front-End Planning tool, and, together with the PDRI, serves as a framework to accomplish sustainability in an infrastructure project while improving the performance of the project and enhancing stakeholder involvement. This rating system can be used throughout the entire lifecycle of a project; however, it has been proved that more benefits can be obtained if the framework is followed at early stages. Adding sustainability criteria at the FEP phase of a project can result in significant cost savings compared to conventional projects.

According to the matrix developed in this chapter, the scope definition categories from the PDRIs are very correlated with all presented Envision™ credits. It is very effective to connect the entire scope of a project with sustainability objectives. Envision™ goals like the improvement of the community's life quality, the engagement of stakeholders, and the pursuit of the best project solution can be accomplished by properly defining the scope of the project at FEP phases. The existing synergies between PDRI and Envision™ have been demonstrated and supported through statistical analysis. An ordered probit analysis confirmed a positive synergy between the success of sustainable infrastructure projects and multiple variables: (1) the awareness of sustainability procedures in the project team, (2) the project value in US$, (3) the financial performance of the project, and (4) the effectiveness of change management in the project. Envision™ provides a standardized FEP process that puts in priority the sustainability of the entire project's lifecycle. This rating system reduces risks and assures quality since it offers four levels of sustainability certifications. Thus, it helps reducing unexpected costs, change orders, and schedules. Therefore, from the research findings in this chapter and the participation of construction industry professionals, it can be established that the Envision™ rating system and the PDRI complement each other. The Envision-PDRI stakeholders' matrix presented in Table 8 works as a coherent baseline for sustainable project management of infrastructure projects.

CHAPTER V

V.1. Research Summary

To assess the need of integrating Front-End Planning (FEP) and sustainability techniques for civil infrastructure projects into STEM curricula, this research first conducted a Problem-Based Learning (PBL) activity with 45 STEM undergraduate and graduate students at the FIU Department of Engineering and Computing. The students were also surveyed with a pre- and post-course questionnaire. The data obtained from this section allowed the author to understand the strengths and weaknesses of the PBL activity in terms of improving students' knowledge and ability to work with FEP and SI tools. Additionally, the results helped in identifying the students' opinions on the convenience of coupling FEP and SI, and their interest in including these novel topics in the STEM curricula. It was determined that 87% of the students agreed with the importance of infrastructure projects to the built environment and the integration of sustainability practices during the FEP phases of these projects. Moreover, more than 84% of the class indicated an interest in integrating SI and FEP in their studies. Finally, it was concluded that the presented PBL activity positively impacted students and it is a strong candidate for future implementation across other disciplines and institutions.

To investigate the correlation between Envision™ and the PDRI tools for infrastructure projects, the author conducted an in-depth investigation. Each Envision™ credit was manually analyzed to determine its sustainable requirements and its application during Front-End Planning. The results were presented in a conceptual matrix that clearly demonstrated the Envision-PDRI synergies. Two frameworks were created, one for Envision™ and the PDRI for small infrastructure projects, and one for Envision™ and the

PDRI for large infrastructure projects. Then, as a supportive investigation, multiple Envision™ projects were used to validate the created frameworks.

Additional validation to previous results was obtained by surveying 109 stakeholders. Their responses were analyzed through a threshold model, which allowed the author to elaborate a handier matrix that correlated six key elements from the PDRI tools and twenty Envision™ credits. It was concluded that multiple synergies existed between the scope definition categories from the PDRI tools and the Envision™ rating system. These synergies were supported through an ordered probit analysis, which confirmed a positive relationship between the success of a sustainable infrastructure project and multiple variables (i.e. the project value, its financial performance, and its change management performance). Overall, the research results and the participation of construction industry professionals and students led to the conclusion that Envision™ and the PDRI tools complement each other.

V.2. Contribution To Knowledge

Findings in this research reveal that students believe front-end planning and sustainability of infrastructure projects (horizontal construction projects) are extremely important divisions that need to be discussed in STEM curricula. Additionally, this research paves the way for the future workforce to understand the criticality of infrastructure sustainability accreditation (i.e. Envision™ Sustainability Professional – ENV SP) and understand the importance of Front-End Planning in infrastructure projects. The study also highlights the importance of the synergy between FEP and Envision™ to the construction industry given that such tools do not focus solely on preserving the environment, but also nurture potential cost savings, limited change orders as well as improvements to the health and wellbeing of the local population. It is critical to developing an informed and skillful future engineering workforce that understands and implements FEP and sustainability tools, in order to achieve more sustainable and successful projects. And, from an industry perspective, the stakeholders' matrix framework obtained in this research will support project teams in planning, assessing risks, and managing sustainable infrastructure projects by demonstrating how the Envision™ rating system can assist in diligent Front-End Planning, and vice versa. The Envision-PDRI frameworks presented in this study work as a coherent baseline for sustainable project management of infrastructure projects. In addition, the matrices advise project stakeholders to focus more on elements that have a higher impact on the performance of a project and aids in a detailed scope definition by reducing uncertainty and risks associated with the project.

V.3. Limitations and Future Studies

This research assessed the existing synergies between the Envision™ rating system and the Project Definition Rating Index (PDRI), as well as embraced them for both the industry and academia. However, there were some limitations when conducting the research, as well as possibilities of future work. These are going to be divided into chapters:

- *Chapter II*: The limitations on this chapter included: (1) the sample of participants was limited to construction management students, (2) the sample was limited to students at a single Hispanic-Serving Institution and does not necessarily represent the entire US population; (3) the scope of the experiment only considered applications in the city of Miami, which does not necessarily align with potential results when considering applications in other cities, and (4) the sample was not evenly distributed across all experience levels. Thus, some recommendations for future work are: (1) Include participants with more than seven years of experience, which are underrepresented in this study, (2) Include a larger number of participants from other relevant majors, i.e. civil engineering, transportation engineering, civil infrastructure management, and architecture; (3) Integrate the module into a hybrid/in-person environment to improve participant's engagement with the activity; (4) Invite industry experts to serve as coaches during the interactive parts of the PBL activity; (5) Include real Envision™-certified projects as case studies for the PBL activity, so that students can also learn more about the rating system and how it is applied. This way they can feel more encouraged into becoming Envision™ Sustainability Professionals (ENV SP); and (6) Improve the PBL activity in a way that it includes specific considerations, i.e. location of the project, the codes and standards that apply to it, and climate and site specifications, so that it can be transferable to other universities in different locations in the US.

- *Chapter III*: Some limitations were encountered in this chapter, including (1) the in-depth analysis of each Envision™ and PDRI element may be considered subjective due to self-judgment, (2) the responses from the stakeholders on the case-study surveys may also be subjective due to personal opinions. However, previous research and the involvement of construction and engineering professionals supported the results. The integration of Envision™ with the PDRI tools is just part of the first step in ensuring project success. Thus, as future studies, it is recommended to investigate how all the phases of Infrastructure Project Management can complement Envision™ requirements, and vice versa.

- *Chapter IV*: This chapter's limitations included that the responses to the survey may be considered subjective because of personal opinions and self-judgments. However, the authors believe that the literature review of the study and the relevant findings support valid judgments. Another research limitation was that not all Envision™ credits and PDRI elements were included in the study. Only the most important ones were selected for this chapter to avoid discouraging participants and to elaborate a handier framework. Thus, it is suggested as future research to include all possible elements from both the Envision™ rating system and the PDRI. Also, future studies should investigate how the Envision™ rating system can aid during all other phases of a project life cycle, not only during FEP. Finally, this chapter is considered the first phase of a continuing study, and the information from it will be used to develop a unified tool that will guide construction stakeholders in integrating sustainability during the FEP phases of infrastructure projects.

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APPENDICES

APPENDIX A

PDRI Infrastructure Sections, Categories and Elements. Source: CII (2013)

I. BASIS OF PROJECT DECISION

A. Project Strategy
- A1 Need & Purpose Documentation
- A2 Investment Studies & Alternatives Assessments
- A3 Key Team Member Coordination
- A4 Public Involvement

B. Owner/Operator Philosophies
- B1 Design Philosophy
- B2 Operating Philosophy
- B3 Maintenance Philosophy
- B4 Future Expansion & Alteration Considerations

C. Project Funding and Timing
- C1 Funding & Programming
- C2 Preliminary Project Schedule
- C3 Contingencies

D. Project Requirements
- D1 Project Objectives Statement
- D2 Functional Classification & Use
- D3 Evaluation of Compliance Requirements
- D4 Existing Environmental Conditions
- D5 Site Characteristics Available vs. Required
- D6 Dismantling & Demolition Requirements
- D7 Determination of Utility Impacts
- D8 Lead/Discipline Scope of Work

E. Value Analysis
- E1 Value Engineering Procedures
- E2 Design Simplification
- E3 Material Alternatives Considered
- E4 Constructability Procedures

II. BASIS OF DESIGN

F. Site Information
- F1 Geotechnical Characteristics
- F2 Hydrological Characteristics
- F3 Surveys & Mapping
- F4 Permitting Requirements
- F5 Environmental Documentation
- F6 Environmental Commitments & Mitigation
- F7 Property Descriptions
- F8 Right-of-Way Mapping & Site Issues

G. Location and Geometry
- G1 Schematic Layouts
- G2 Horizontal & Vertical Alignment
- G3 Cross-Sectional Elements
- G4 Control of Access

H. Associated Structures and Equipment
- H1 Support Structures
- H2 Hydraulic Structures
- H3 Miscellaneous Elements
- H4 Equipment List
- H5 Equipment Utility Requirements

I. Project Design Parameters
- I1 Capacity
- I2 Safety & Hazards
- I3 Civil/Structural
- I4 Mechanical/Equipment
- I5 Electrical/Controls
- I6 Operations/Maintenance

III. EXECUTION APPROACH

J. Land Acquisition Strategy
- J1 Local Public Agencies Contracts & Agreements
- J2 Long-Lead Parcel & Utility Adjustment Identification & Acquisition
- J3 Utility Agreement & Joint-Use Contracts
- J4 Land Appraisal Requirements
- J5 Advance Land Acquisition Requirements

K. Procurement Strategy
- K1 Project Delivery Method & Contracting Strategies
- K2 Long-Lead/Critical Equipment & Materials Identification
- K3 Procurement Procedures & Plans
- K4 Procurement Responsibility Matrix

L. Project Control
- L1 Right-of-Way & Utilities Cost Estimates
- L2 Design & Construction Cost Estimates
- L3 Project Cost Control
- L4 Project Schedule Control
- L5 Project Quality Assurance & Control

M. Project Execution Plan
- M1 Safety Procedures
- M2 Owner Approval Requirements
- M3 Documentation/Deliverables
- M4 Computing & CADD/Model Requirements
- M5 Design/Construction Plan & Approach
- M6 Intercompany & Interagency Coordination & agreements
- M7 Work Zone and Transportation Plan
- M8 Project Completion Requirements

APPENDIX B

PDRI Small Infrastructure Sections, Categories and Elements. Source: CII (2016)

I. BASIS OF PROJECT DECISION

A. Project Alignment

- A1. Need and Purpose Statement
- A2. Key Project Participants
- A3. Public Involvement
- A4. Project Philosophies
- A5. Project Funding
- A6. Preliminary Project Schedule

B. Project Requirements

- B1. Functional Classification and Use
- B2. Physical Site
- B3. Dismantling and Demolition Requirements

II. BASIS OF DESIGN

C. Design Guidance

- C1. Lead/Discipline Scope of Work
- C2. Project Codes and Standards
- C3. Topographical Surveys and Mapping
- C4. Project Site Assessment
- C5. Environmental and Regulatory Consideration
- C6. Value Analysis
- C7. Construction Input

D. Project Design Parameters

- D1. Capacity
- D2. Design for Safety and Hazards
- D3. Civil and Structural
- D4. Mechanical and Equipment
- D5. Electrical and Controls
- D6. Operations and Maintenance

E. Location and Geometry

- E1. Schematic Layouts
- E2. Alignment and Cross-section
- E3. Control of Access

F. Associated Structures and Equipment

- F1. Support Structures
- F2. Hydraulic Structures
- F3. Miscellaneous Elements
- F4. Equipment List

III. EXECUTION APPROACH

G. Execution Requirements

- G1. Land Acquisition Strategy
- G2. Utility Adjustment Strategy
- G3. Procurement Strategy
- G4. Owner Approval Requirements
- G5. Intercompany and Interagency Coordination

H. Engineering/Construction Plan and Approach

- H1. Design/Construction Plan and Approach
- H2. Project Cost Estimate and Cost Control
- H3. Project Schedule and Schedule Control
- H4. Project Quality Assurance and Control
- H5. Safety, Work Zone, and Transportation Plan
- H6. Project Commissioning/Closeout

APPENDIX C

Envision™ v3 Credit List. Source: ISI (2018)

Quality Of Life
14 Credits

WELLBEING
- **QL1.1** Improve Community Quality of Life
- **QL1.2** Enhance Public Health & Safety ✎
- **QL1.3** Improve Construction Safety (N)
- **QL1.4** Minimize Noise & Vibration
- **QL1.5** Minimize Light Pollution
- **QL1.6** Minimize Construction Impacts (N)

MOBILITY
- **QL2.1** Improve Community Mobility & Access
- **QL2.2** Encourage Sustainable Transportation
- **QL2.3** Improve Access & Wayfinding

COMMUNITY
- **QL3.1** Advance Equity & Social Justice (N)
- **QL3.2** Preserve Historic & Cultural Resources
- **QL3.3** Enhance Views & Local Character
- **QL3.4** Enhance Public Space & Amenities

QL0.0 Innovate or Exceed Credit Requirements

Leadership
12 Credits

COLLABORATION
- **LD1.1** Provide Effective Leadership & Commitment
- **LD1.2** Foster Collaboration & Teamwork
- **LD1.3** Provide for Stakeholder Involvement
- **LD1.4** Pursue Byproduct Synergies

PLANNING
- **LD2.1** Establish a Sustainability Management Plan
- **LD2.2** Plan for Sustainable Communities (N)
- **LD2.3** Plan for Long-Term Monitoring & Maintenance
- **LD2.4** Plan for End-of-Life ✎

ECONOMY
- **LD3.1** Stimulate Economic Prosperity & Development
- **LD3.2** Develop Local Skills & Capabilities
- **LD3.3** Conduct a Life-Cycle Economic Evaluation (N)

LD0.0 Innovate or Exceed Credit Requirements

Resource Allocation
14 Credits

MATERIALS
- **RA1.1** Support Sustainable Procurement Practices
- **RA1.2** Use Recycled Materials
- **RA1.3** Reduce Operational Waste
- **RA1.4** Reduce Construction Waste (N)
- **RA1.5** Balance Earthwork On Site

ENERGY
- **RA2.1** Reduce Operational Energy Consumption
- **RA2.2** Reduce Construction Energy Consumption (N)
- **RA2.3** Use Renewable Energy
- **RA2.4** Commission & Monitor Energy Systems

WATER
- **RA3.1** Preserve Water Resources ✎
- **RA3.2** Reduce Operational Water Consumption
- **RA3.3** Reduce Construction Water Consumption (N)
- **RA3.4** Monitor Water Systems

RA0.0 Innovate or Exceed Credit Requirements

Natural World
14 Credits

SITING
- **NW1.1** Preserve Sites of High Ecological Value
- **NW1.2** Provide Wetland & Surface Water Buffers
- **NW1.3** Preserve Prime Farmland
- **NW1.4** Preserve Undeveloped Land

CONSERVATION
- **NW2.1** Reclaim Brownfields (N)
- **NW2.2** Manage Stormwater ✎
- **NW2.3** Reduce Pesticide & Fertilizer Impacts
- **NW2.4** Protect Surface & Groundwater Quality

ECOLOGY
- **NW3.1** Enhance Functional Habitats ✎
- **NW3.2** Enhance Wetland & Surface Water Functions
- **NW3.3** Maintain Floodplain Functions
- **NW3.4** Control Invasive Species
- **NW3.5** Protect Soil Health

NW0.0 Innovate or Exceed Credit Requirements

Climate and Resilience
10 Credits

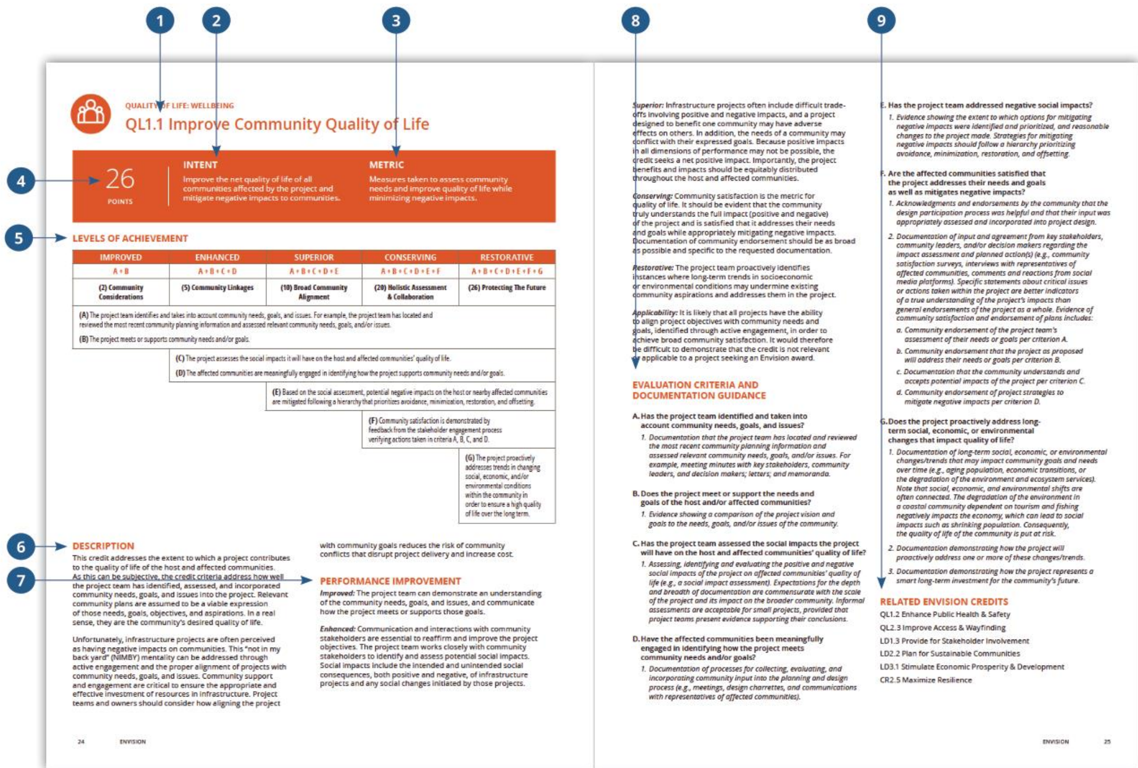
EMISSIONS
- **CR1.1** Reduce Net Embodied Carbon ✎
- **CR1.2** Reduce Greenhouse Gas Emissions
- **CR1.3** Reduce Air Pollutant Emissions

RESILIENCE
- **CR2.1** Avoid Unsuitable Development ✎
- **CR2.2** Assess Climate Change Vulnerability
- **CR2.3** Evaluate Risk & Resilience (N)
- **CR2.4** Establish Resilience Goals and Strategies (N)
- **CR2.5** Maximize Resilience ✎
- **CR2.6** Improve Infrastructure Integration

CR0.0 Innovate or Exceed Credit Requirements

✎ Rewritten
(N) New

Navigating Envision™ v3 Credits. Source: ISI (2018)



1. **Credit Title and Identification Number**
   Includes the two-letter code identifying the category, and a number identifying the credit.
2. **Intent**
   The purpose of the credit.
3. **Metrics**
   How the credit will be measured.
4. **Total Possible Points**
   Value of the highest level of achievement.
5. **Levels of Achievement**
   Brief description of the requirements necessary to meet each level of achievement. Levels increase in their contribution toward sustainability.
6. **Description**
   Explanation of the sustainability issue addressed by the credit and its significance in infrastructure projects.
7. **Performance Improvement**
   Sets the benchmark for performance. It also provides general strategy for performance improvements.
8. **Evaluation Criteria and Documentation Guidance**
   Specifies the questions that the project must address in order to meet the requirements of a level of achievement. It also provides examples of the types of documents that may be submitted for verification in order to demonstrate that requirements were met.
9. **Related Envision Credits**
   Envision credits which may share documentation requirements, or may relate in a symbiotic way in order to meet level of achievement requirements.

Envision v3 categories, credits, and points. Source: ISI (2018)

Category	Subcategory	Credit	Improved	Enhanced	Superior	Conserving	Restorative	Maximum Points
Quality of Life	Wellbeing	QL1.1 Improve Community Quality of Life	2	5	10	20	26	200
		QL1.2 Enhance Public Health & Safety	2	7	12	16	20	
		QL1.3 Improve Construction Safety	2	5	10	14	—	
		QL1.4 Minimize Noise & Vibration	1	3	6	10	12	
		QL1.5 Minimize Light Pollution	1	3	6	10	12	
		QL1.6 Minimize Construction Impacts	1	2	4	8	—	
	Mobility	QL2.1 Improve Community Mobility	1	3	7	11	14	
		QL2.2 Encourage Sustainable Transportation	—	5	8	12	16	
		QL2.3 Improve Access & Wayfinding	1	5	9	14	—	
	Community	QL3.1 Advance Equity & Social Justice	3	6	10	14	18	
		QL3.2 Preserve Historic & Cultural Resources	—	2	7	12	18	
		QL3.3 Enhance Views & Local Character	1	3	7	11	14	
		QL3.4 Enhance Public Space & Amenities	1	3	7	11	14	
Leadership	Collaboration	LD1.1 Provide Effective Leadership & Commitment	2	5	12	18	—	182
		LD1.2 Foster Collaboration & Teamwork	2	5	12	18	—	
		LD1.3 Provide for Stakeholder Involvement	3	6	9	14	18	
		LD1.4 Pursue Byproduct Synergies	3	6	12	14	18	
	Planning	LD2.1 Establish a Sustainability Management Plan	4	7	12	18	—	
		LD2.2 Plan for Sustainable Communities	4	6	9	12	16	
		LD2.3 Plan for Long-Term Monitoring & Maintenance	2	5	8	12	—	
		LD2.4 Plan for End-of-Life	2	5	8	14	—	
	Economy	LD3.1 Stimulate Economic Prosperity & Development	3	6	12	20	—	
		LD3.2 Develop Local Skills & Capabilities	2	4	8	12	16	
		LD3.3 Conduct a Life-Cycle Economic Evaluation	5	7	10	12	14	
Resource Allocation	Materials	RA1.1 Support Sustainable Procurement Practices	3	6	9	12	—	196
		RA1.2 Use Recycled Materials	4	6	9	16	—	
		RA1.3 Reduce Operational Waste	4	7	10	14	—	
		RA1.4 Reduce Construction Waste	4	7	10	16	—	
		RA1.5 Balance Earthwork On Site	2	4	6	8	—	
	Energy	RA2.1 Reduce Operational Energy Consumption	6	12	18	26	—	
		RA2.2 Reduce Construction Energy Consumption	1	4	8	12	—	
		RA2.3 Use Renewable Energy	5	10	15	20	24	
		RA2.4 Commission & Monitor Energy Systems	3	6	12	14	—	
	Water	RA3.1 Preserve Water Resources	3	5	7	9	12	
		RA3.2 Reduce Operational Water Consumption	4	9	13	17	22	
		RA3.3 Reduce Construction Water Consumption	1	3	5	8	—	
		RA3.4 Monitor Water Systems	1	3	6	12	—	
Natural World	Siting	NW1.1 Preserve Sites of High Ecological Value	2	6	12	16	22	232
		NW1.2 Provide Wetland & Surface Water Buffers	2	5	10	16	20	
		NW1.3 Preserve Prime Farmland	—	2	8	12	16	
		NW1.4 Preserve Undeveloped Land	3	8	12	18	24	
	Conservation	NW2.1 Reclaim Brownfields	11	13	16	19	22	
		NW2.2 Manage Stormwater	2	4	9	17	24	
		NW2.3 Reduce Pesticide & Fertilizer Impacts	1	2	5	9	12	
		NW2.4 Protect Surface & Groundwater Quality	2	5	9	14	20	
	Ecology	NW3.1 Enhance Functional Habitats	2	5	9	15	18	
		NW3.2 Enhance Wetland & Surface Water Functions	3	7	12	18	20	
		NW3.3 Maintain Floodplain Functions	1	3	7	11	14	
		NW3.4 Control Invasive Species	1	2	6	9	12	
		NW3.5 Protect Soil Health	—	3	4	6	8	
Climate and Resilience	Emissions	CR1.1 Reduce Net Embodied Carbon	5	10	15	20	—	190
		CR1.2 Reduce Greenhouse Gas Emissions	8	13	18	22	26	
		CR1.3 Reduce Air Pollutant Emissions	2	4	9	14	18	
	Resilience	CR2.1 Avoid Unsuitable Development	3	6	8	12	16	
		CR2.2 Assess Climate Change Vulnerability	8	14	18	20	—	
		CR2.3 Evaluate Risk and Resilience	11	18	24	26	—	
		CR2.4 Establish Resilience Goals and Strategies	—	8	14	20	—	
		CR2.5 Maximize Resilience	11	15	20	26	—	
		CR2.6 Improve Infrastructure Integration	2	5	9	13	18	
							Maximum TOTAL Points	1,000

APPENDIX D

Student's survey – IRB-20-0540

Assessing the Pedagogical Needs to Couple Front-End Planning Tools with Sustainable Infrastructure Projects

Thank you for participating in this brief 5-minute survey that will be used to identify STEM students' understanding and knowledge of **Front-End Planning (FEP) tools and Sustainable Infrastructure Projects**. This study also aims to determine potential correlations between infrastructure rating systems with FEP practices.

You must be 18 or older to participate in the study. Your participation in this study is strictly voluntary. You have the right not to answer any question and to quit the survey at any time. There will be no penalty if you choose not to participate or to withdraw from the survey. Your decision of whether or not to participate in this study will not affect your status at FIU. There are no foreseeable risks or discomforts associated with your participation. Your completion and submission of the questionnaire indicate your consent to participate in the study.

Please note that all responses will be analyzed, and aggregated results will be shared with the project investigator. Results will only be shared in aggregate. Personal and identifying information will be kept confidential and will not be disclosed to anyone outside of the study, except as required by law. Responses will be independent of your academic record and will not affect your standing at FIU.

Please write the first 3 letters of the name of the city you were born, followed by the last 4 numbers of your mobile (i.e. MIA3086)

____

Project scope is the project team's understanding of what goes into a project and what factors define its success.

How familiar are you with defining the **scope of a project**?

◯ Extremely familiar (I took a full course about this or have been using it in professional setting)

◯ I have a fair idea

◯ Very little

◯ Never heard of it before

◯ Other: (Please specify) ____

Would **defining a project** before a project's kickoff meeting (start of Construction) **support its success**?

◯ Extremely likely

◯ Slightly likely

◯ Neither likely nor unlikely

◯ Slightly unlikely

◯ Extremely unlikely

Do you think that **project stakeholders** including contractors and consultants are **critical to be involved very early in the project** even before the design is completed? Or are they more effective once the project design is completed and the construction is ready to proceed?

- ○ Very early in the project
- ○ Once the Design has been completed
- ○ After the project has started
- ○ Doesn't make a difference
- ○ They are not important at all

Do you think that **team alignment** between project stakeholders including designers, contractors, and consultants (work in sync to accomplish a common purpose) **is important for a project?**

- ○ Extremely important
- ○ Very important
- ○ Moderately important
- ○ Slightly important
- ○ Not at all important

Is there a difference between **Front-End Planning** and traditional **Planning/Scheduling**?

- ◯ Front-End Planning is exactly like Planning/Scheduling
- ◯ Front-End Planning is different than Planning/Scheduling
- ◯ I'm not sure if there are differences

How familiar are you with **Front-End Planning tools**? (i.e. risk assessment, team alignment, change management)

- ◯ Extremely familiar
- ◯ Very familiar
- ◯ Moderately familiar
- ◯ Slightly familiar
- ◯ Not familiar at all

How much do you know about **infrastructure projects**?

- ○ I took a full course about infrastructure projects
- ○ I have worked at an infrastructure project
- ○ I have a fair idea
- ○ Very little knowledge about infrastructure projects
- ○ Never heard of infrastructure projects before

How important do you consider that **infrastructure projects** are to the built environment and the communities?

- ○ Extremely important
- ○ Very important
- ○ Moderately important
- ○ Slightly important
- ○ Not at all important

How familiar are you with **Sustainability and Sustainable Construction**?

- ◯ Extremely familiar
- ◯ Very familiar
- ◯ Moderately familiar
- ◯ Slightly familiar
- ◯ Not familiar at all

Which **sustainable rating system** are you familiar with?

- ☐ Envision
- ☐ GreenRoads
- ☐ INVEST
- ☐ LEED
- ☐ Living Building Challenge
- ☐ Other: (Please specify)

____

As there is a sustainable rating system for buildings (LEED), there is also a sustainable rating system that assesses the triple bottom line of **infrastructure projects** named **Envision**.
How familiar are you with the Sustainable Infrastructure Rating System **Envision**?

○ Extremely familiar

○ Very familiar

○ Moderately familiar

○ Slightly familiar

○ Not familiar at all

Civil Infrastructures provide the basis for personal security and public health, provide drinking water, handle waste, and allow building and industrial projects to connect with utilities. Do you believe it is important to integrate **sustainability criteria during the design, construction, and operation of an infrastructure project**?

○ Extremely important

○ Very important

○ Neither Important or unimportant

○ Slightly unimportant

○ Extremely unimportant

Do you think that **sustainability criteria** can support a project's performance, in terms of **cost, schedule, and change orders**?

- ◯ Extremely likely
- ◯ Slightly likely
- ◯ Neither likely nor unlikely
- ◯ Slightly unlikely
- ◯ Extremely unlikely

Would you be interested to learn about **Sustainable Infrastructure projects** in your construction or engineering studies?

- ◯ Extremely likely
- ◯ Slightly likely
- ◯ Neither likely nor unlikely
- ◯ Slightly unlikely
- ◯ Extremely unlikely

Please select all applicable reasons for choosing your answer to the previous question.

- ☐ Every contractor and engineer should know new methods and designs
- ☐ I want to focus my career on infrastructure management
- ☐ Never heard of it before
- ☐ I don’t think it is important
- ☐ Other (Please specify)

____

Would you **implement or define any of the elements** listed below **before the completion of the project's design** at a stage where the owner is still considering to pursue or even develop the project?

	Definitely yes	Probably yes	Might or might not	Probably not	Definitely not
Project Strategy	○	○	○	○	○
Owner Philosophies	○	○	○	○	○
Project Funding and Timing	○	○	○	○	○
Project Requirements	○	○	○	○	○
Value Analysis	○	○	○	○	○
Design Guidance	○	○	○	○	○
Project Design Parameters	○	○	○	○	○
Location and Geometry of the project	○	○	○	○	○
Associated Structures and Equipment	○	○	○	○	○

Would you be interested to learn about **Front-End Planning for infrastructure projects** in your construction or engineering studies?

- Extremely likely
- Slightly likely
- Neither likely nor unlikely
- Slightly unlikely
- Extremely unlikely

Please select all applicable reasons for choosing your answer to the previous question.

- Every contractor and engineer should know new methods and designs
- I want to focus my career on infrastructure management
- Never heard of it before
- I don’t think it is important
- Other (Please specify)

____

If **Front-End Planning for Sustainable Infrastructures** would be integrated into one of your courses, do you see it as a complete course or a portion of a course?

- ○ Complete Course
- ○ A portion of a Course
- ○ Neither Complete Course nor a Portion
- ○ Other: (Please specify) ____

Front-End Planning is a process for developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. Good FEP can result in 10% cost reductions, 7% schedule reductions, and 5% change reduction. Thus, introducing FEP on infrastructure projects that pursue a **sustainability certification** can aid in those additional efforts that these kinds of projects need, during the planning, design, construction, and maintenance phases.

Please rate your interest to include the following tools and techniques in your **construction and engineering curriculum**: (on a scale from 1= Not Interested to 5= Extremely interested)

	Not Interested 1	Probably Interested 2	Interested 3	Highly Interested 4	Extremely Interested 5
Sustainability for infrastructure projects					
Front-End Planning for infrastructure projects					
Infrastructure Engineering Management					

Would you consider that the **Front-End Planning activity** you just did, changed the way you perceived the **pre-project planning of an infrastructure project**?

- Extremely likely
- Slightly likely
- Neither likely nor unlikely
- Slightly unlikely
- Extremely unlikely

APPENDIX E

Stakeholders' survey – IRB-20-0521

Pre-project planning for Sustainable Infrastructure

Welcome to the survey!

The purpose of the study is **to investigate the correlations between the sustainable rating systems of infrastructure projects (i.e. Envision), and pre-project planning tools** to help infrastructure projects to meet their budgeted cost and schedule.
The survey may take about 8-10 minutes to be completed. If you have concerns or questions about the research, please email **Valentina Ferrer** at vferr035@fiu.edu or **Dr. Mohamed ElZomor** at melzomor@fiu.edu. Thank you in advance for your time.

The answers to this survey are strictly confidential- the dataset is anonymous, and no information of the responders will be kept. Your participation is voluntary. You may choose not to take the survey, to stop responding at any time, or to skip any questions that you do not want to answer. You must be at least 18 years of age to participate in this study. Your completion of the survey serves as your voluntary agreement to participate in this research project.

A.1 What is the **highest degree** you have received?

- ○ High school degree
- ○ Associate degree
- ○ Bachelor's degree in college (4-year)
- ○ Advanced degree (Masters/PhD)
- ○ Prefer not to answer

A.2 What is your current **primary role**? (select one only)

- ○ Architect / Project Engineer
- ○ Contractor
- ○ Consultant
- ○ Project Manager
- ○ Program Manager / Owner / Director
- ○ Other (please specify) ____________________

A.3 What **types of projects** have you worked on?

- ☐ Residential
- ☐ Commercial
- ☐ Industrial
- ☐ Infrastructures Systems
- ☐ Other (Please Specify): ______________________

A.4 How long is your **professional experience** in this industry?

- ○ 0 to 3 years
- ○ 3 to 7 years
- ○ 7 to 10 years
- ○ More than 10 years
- ○ Prefer not no answer

A.5 Have you **utilized any pre-project planning tools** in your current or previous projects?

- ○ Yes
- ○ No

A.6 Which **sustainability rating system** are you familiar with? (Select all that apply)

- ☐ Envision
- ☐ GreenRoads
- ☐ INVEST
- ☐ LEED
- ☐ Living Building Challenge
- ☐ Other: (Please Specify)

____

A.7 Has your organization ever pursued a **sustainability certification for an infrastructure project**?

- ○ Yes
- ○ No
- ○ Prefer not to answer

A.8 What is your **gender**?

- ○ Male
- ○ Female
- ○ Other
- ○ Prefer not to answer

In this section, you will be asked about **the correlations** between sustainability considerations and project planning stages. **A correlation is a mutual relationship or connection between two or more criteria.** Please consider this definition when answering this section of the survey.

B.1 The **project strategy** is the first stage in a project that identifies the project's purpose and need, stakeholders, and activities. Which of the following do you think are correlated to the **Project Strategy of infrastructure projects**? *Please select all appropriate answers*

- ☐ Encourage Sustainable Transportation
- ☐ Preserve Historic and Cultural Resources, and Ensure Equity and Social Justice
- ☐ Provide Effective Leadership & Commitment through Collaboration and Teamwork
- ☐ Pursue By-Product Synergy (industrial ecology)
- ☐ Establish a Sustainability Management Plan
- ☐ Use Recycled Materials, and Reduce Construction Waste
- ☐ Preserve Sites of High Ecological Value
- ☐ Enhance Wetland & Surface Water Functions

B.2 The **project philosophies** define how is the project going to achieve the overall performance requirements (i.e. design, operations, maintenance goals). Which of the following do you think can correlate to a **Project Philosophies** of infrastructure projects? *Please select all appropriate answers*

- [ ] Encourage Sustainable Transportation)
- [ ] Preserve Historic and Cultural Resources, and Ensure Equity and Social Justice
- [ ] Provide Effective Leadership & Commitment through Collaboration and Teamwork
- [ ] Pursue By-Product Synergy (industrial ecology)
- [ ] Establish a Sustainability Management Plan
- [ ] Use Recycled Materials, and Reduce Construction Waste
- [ ] Preserve Sites of High Ecological Value
- [ ] Enhance Wetland & Surface Water Functions

B.3 **Project funding and timing** is the stage of the project where funding sources are identified, budgeted, and documented (i.e. cost estimates). Which of the following do you think can correlate to a **Project Funding and Timing** of infrastructure projects? *Please select all appropriate answers*

- ☐ Encourage Sustainable Transportation
- ☐ Preserve Historic and Cultural Resources, and Ensure Equity and Social Justice
- ☐ Provide Effective Leadership & Commitment through Collaboration and Teamwork
- ☐ Pursue By-Product Synergy (industrial ecology)
- ☐ Establish a Sustainability Management Plan
- ☐ Use Recycled Materials, and Reduce Construction Waste
- ☐ Preserve Sites of High Ecological Value
- ☐ Enhance Wetland & Surface Water Functions

B.4 **Project requirements** address high-level requirements informing the basis of project design. Such as project objectives statements, existing environmental conditions, site characteristics, functional classification, and use. Which of the following do you think are correlated to the **project requirements** of infrastructure projects? *Please select all appropriate answers*

- ☐ Encourage Sustainable Transportation
- ☐ Preserve Historic and Cultural Resources, and Ensure Equity and Social Justice
- ☐ Provide Effective Leadership & Commitment through Collaboration and Teamwork
- ☐ Pursue By-Product Synergy (industrial ecology)
- ☐ Establish a Sustainability Management Plan
- ☐ Use Recycled Materials, and Reduce Construction Waste
- ☐ Preserve Sites of High Ecological Value
- ☐ Enhance Wetland & Surface Water Functions

B.5 **Design guidance** is the stage of the project where the elements required to support detailed design are identified (i.e. environmental conditions, topographical surveys, project standards, etc). Which of the following do you think can correlate to the **design guidance** of infrastructure projects? *Please select all appropriate answers*

- ☐ Encourage Sustainable Transportation
- ☐ Preserve Historic and Cultural Resources, and Ensure Equity and Social Justice
- ☐ Provide Effective Leadership & Commitment through Collaboration and Teamwork
- ☐ Pursue By-Product Synergy (industrial ecology)
- ☐ Establish a Sustainability Management Plan
- ☐ Use Recycled Materials, and Reduce Construction Waste
- ☐ Preserve Sites of High Ecological Value
- ☐ Enhance Wetland & Surface Water Functions

B.6 The **location and geometry** of a project consider schematic layouts, alignments, cross-sections, and control of access information that are important to the design success of the project. Which of the following do you think can correlate to **the location and geometry** of infrastructure projects? *Please select all appropriate answers*

- ☐ Encourage Sustainable Transportation
- ☐ Preserve Historic and Cultural Resources, and Ensure Equity and Social Justice
- ☐ Provide Effective Leadership & Commitment through Collaboration and Teamwork
- ☐ Pursue By-Product Synergy (industrial ecology)
- ☐ Establish a Sustainability Management Plan
- ☐ Use Recycled Materials, and Reduce Construction Waste
- ☐ Preserve Sites of High Ecological Value
- ☐ Enhance Wetland & Surface Water Functions

B.7 In this question, kindly **identify** the correlation between the project planning criteria and some of the sustainable infrastructure criteria shown in the matrix below.

Please mark all that apply.

	Project Strategy (1)	Project Philosophies (17)	Project Funding and Timing (18)	Project Requirements (19)	Design Guidance (20)	Schematic Layouts (21)
Improve Community Quality of Life (1)	☐	☐	☐	☐	☐	☐
Stimulate Economic Prosperity & Development (19)	☐	☐	☐	☐	☐	☐
Use Renewable Energy, and Reduce Water Consumption (20)	☐	☐	☐	☐	☐	☐
Manage Stormwater (21)	☐	☐	☐	☐	☐	☐
Reduce Greenhouse Gas Emissions (22)	☐	☐	☐	☐	☐	☐
Evaluate Risk and Maximize Resilience (23)	☐	☐	☐	☐	☐	☐

This is the last page of the survey.

Please answer these quick questions and then click on the right arrow at the bottom so your response is recorded.

In this section please consider **a single infrastructure project** you have worked on **that received an infrastructure sustainable certification** (Envision) otherwise please consider **a project that included any sustainable criteria**.
Please answer each question thinking about this specific project.

C.1 Have you ever been part of an **infrastructure project** that has received an **infrastructure sustainable certification** (i.e. Envision)?

◯ Yes

◯ No

C.2 Where is the **location** of the selected project?

▼ Prefer not to answer ... I do not reside in the United States

---

C.3 What is/was the approximate **value (in US $) of the infrastructure project** you selected?

- ◯ < 50,000
- ◯ 50,001 - 1,000,000
- ◯ 1,000,001- 10,000,000
- ◯ 10,000,001 - 50,00,000
- ◯ > 50,000,000
- ◯ Prefer not to answer

C.4 What was the **duration of this infrastructure project**?

- ◯ Up to 6 months
- ◯ 6 to 12 months
- ◯ 12 to 18 months
- ◯ 18 months to 3 years
- ◯ > 3 years
- ◯ Prefer not to answer

C.5 On a scale of 1 to 5 **(being 1 least successful, and 5 most successful)**, how would you qualify the **rate of project success** in the **sustainable infrastructure project** you selected, compared to other projects?

▼ 1 (Least successful) ... Prefer not to answer

C.6 On a scale of 1 to 5 (**1 being far short of expectations, 5 being far exceeding expectations**), how **well was the actual financial performance** of the **sustainable infrastructure project** you selected?

▼ 1 (short of expectations) ... Prefer not to answer

C.7 Based on your experience in infrastructure projects, please specify your level of agreement that the **integration of sustainability criteria during pre-project planning of infrastructure projects can support** the below three **project performances** (Cost, Schedule, Change Orders).

Please rank your answer for from 1 to 5. [1= Strongly Disagree; 5= Strongly Agree]

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Not Applicable
		1	2	3	4	5

Meet the Targeted Project Budget / Cost ()	
Meet Planned Project Schedule ()	
Reduce Design Change Orders ()	