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Refocusing Sustainability Education: Using Students' Reflections on Their Carbon Footprint to Reinforce the Importance of Considering CO_2 Production in the Construction Industry

John Weirs* **and Allan Osborne**

Faculty of Engineering and Environment, Department of Mechanical and Construction Engineering, University of Northumbria at Newcastle, Newcastle upon Tyne, United Kingdom

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***Correspondence:**
John Weirs
john.weirs@northumbria.ac.uk

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The construction industry is the most significant contributor to the UK's CO_2 emissions. Its activities are responsible for an annual output of approximately 45% of the total. This figure highlights the role the industry must play in helping to achieve the UK Government's CO_2 reduction target. It is ergo incumbent on construction-related educators to emphasize this issue and explore ways in which it can be achieved. Unintentional desensitization has resulted in the term 'sustainability,' particularly CO_2 production, being seen by students as just another concept to be studied from a theoretical perspective. Many students fail to grasp its broader implications and how it should affect strategic environmental decisions about construction processes, technologies, and products. To help address this problem, an innovative learning, teaching, and assessment strategy was used with final year undergraduate construction students to improve their level of sustainability literacy. The theory of threshold concepts in the context of transformative learning was used as the baseline philosophy to the study. The approach involved asking students to calculate their carbon footprint and to reflect upon and extrapolate their findings to the construction industry and its practice. Content analysis was performed on the reflective commentaries acquired from student portfolios collected over four academic years. The results showed how the students' reflections on their carbon footprints proved to be an enlightening experience. Terms such as 'shocked by my footprint,' 'surprised at the findings,' and 'change in attitude' were among the contemplative comments. When students linked their findings to the construction industry, phrases such as 'waste generation,' 'technologies,' and 'materials' were some of the concepts considered. By using their personal experiences as a benchmark, students were able to gain a deeper understanding of the causes and consequences of CO_2 production. They also found it more straightforward to relate these issues to the construction industry and its practice. Several recommendations are made to raise the level of sustainability literacy in the construction industry thereby facilitating a potential reduction in worldwide CO_2 production.

Keywords: construction industry, sustainability education, carbon footprint, CO_2 production, reflection

INTRODUCTION

Natural environmental pressures on today's global society are well-documented. Worldwide energy consumption continues to rise. For example, the United States Energy Information Administration [EIA] (2017) predicts there will be a 28% increase in world energy use between 2015 and 2040. Even though the EIA anticipates non-fossil fuels will grow faster in their use than fossil fuels, carbon-based fuels will still account for more than three-quarters of world energy consumption. This situation has resulted in a depletion of the world's natural resources and an increase in carbon emissions. The upper safety limit for atmospheric CO_2, considered to be 350-ppm, was exceeded in mid-1985. It has continued to rise at a steady pace ever since. The concentration of atmospheric CO_2 in December 2019 had broken through the 400-ppm barrier and stood at 411.25-ppm (CO_2Now, 2019).

The construction industry is a major player in terms of energy use and CO_2 production. Buildings alone are thought to contribute approximately one-third of global greenhouse gas emissions, mainly through energy generation using fossil fuels (United Nations, 2010). By 2009, Huang et al. (2018) suggested that the global construction industry was responsible for 5.7 tons of CO_2 emissions. Further analysis of CO_2 emissions from construction activities across several countries found that China had the highest level at 42%, followed by the EU at 18%, and the US third with 13%. Globally, the built environment is responsible for using approximately 3 billion tons of raw materials annually (United Nations, 2012), which accounts for 35% of annual material consumption (Chartered Institute of Building [CIOB], 2013). In the UK this figure is closer to 45% (Chartered Institute of Building [CIOB], 2010), which contributes to 13% of the total global CO_2 emissions (mainly from the embodied energy contained in materials production), with a further 32% of CO_2 emissions coming from the use of buildings (Gibson, 2013).

Huang et al. (2018, pp. 1906) define operational energy in buildings as the energy used for such things as "heating/cooling, ventilation, hot water" suggesting that approximately 80% of the total energy used is operational energy from "the occupied built environment" (Huang et al., 2018; p. 1906). Energy use in the heating and cooling of occupied buildings is suggested to be between 18 and 73%, with space-heating in domestic and commercial properties alone estimated to be 32 and 33% respectively (Ürge-Vorsatz et al., 2015). Ürge-Vorsatz et al. (2015) go on to say that the energy use in the provision of hot water in commercial buildings can be as high at 12% and in residential buildings even higher at 24%.

In the UK, the Department for Communities and Local Government (2014) has suggested that 40% of the energy consumption is a result of the way buildings are used. Cotgrove and Riley (2013) set this figure at nearer 50%, with 7% energy use directly related to the construction process. The findings of the Low Carbon Construction Innovation and Growth Team (HM Government, 2010) indicate that the construction industry produces a total carbon footprint of over 300 million tons. Sharma et al. (2011) suggest the UK construction industry is responsible for half of the energy consumption and CO_2 emissions, with the operational phase of buildings contributing over 50% of greenhouse gas emissions and between 80 and 85% of energy consumption. It is important to note that these figures vary by source. What is clear is that the construction industry contributes significantly to resource depletion through materials usage, waste generation, and CO_2 emissions. The Climate Change Act (HM Government, 2008) is one of the most critical aspects of the UK Government's commitment to sustainable growth by setting a target of an 80% reduction in CO_2 emissions by 2050 (based on CO_2 levels in 1990). Given the impact the construction industry and the built environment has on the natural environment, it must consider areas where contributions can be made to achieve these ambitious reduction targets.

The construction industry must reduce its direct CO_2 production. In support of this endeavor, the current study suggests that universities, *inter alia*, have a role to play by changing their approach to environment and sustainable development education of construction students. Sustainability is all too often diluted in higher education curricula to the mere presentation of theoretical concepts across a myriad of disconnected subject areas. The current study also argues that recognition of the importance of sustainable development and CO_2 reduction by construction undergraduate students can be enhanced by using pedagogic approaches in which sustainability is studied not just as a theoretical concept but as a real-world problem. The current study aims to investigate the viewpoints of undergraduate construction students after they have studied a course on sustainable development, with the objective being to determine if the students would change their behavior toward CO_2 production before and after graduation.

As a result of a four-year study to examine the effectiveness of an innovative pedagogic approach to the sustainability education of construction undergraduate students, findings are presented in the current paper that demonstrate how behaviors affecting CO_2 production can be modified, and sustainability literacy increased. The conclusions drawn reveal a critical missing link between construction-related education, theory, and professional practice, and highlight a pedagogic gap that presently exists that must be recognized by universities and professional, statutory and regulatory bodies (PSRB) worldwide.

Sustainability Education

The UK Government's sustainability strategy identifies sustainability literacy as a core component of knowledge for university graduates (HM Government, 2005). To be *sustainability literate* is to understand the requirements for environmental change combined with the knowledge and skills to contribute to this change (Murray and Cotgrove, 2007). Sustainability education will, therefore, provide students with an appreciation of how their actions will impact in the broader society and provide them with the sustainability literacy required in their professional career (Opoku and Egbu, 2017). Sustainability education will assist students in developing skills in critical thinking and problem-solving to become sustainability literate and to prepare them for the challenge sustainability brings (Hedden et al., 2017). Universities must educate students to understand what sustainability means and to empower their thinking and approaches to solving sustainability problems (Pappas, 2012).

The current study suggests that the term *sustainability*, particularly *CO_2 production*, is seen by many students as just another concept to be studied from a theoretical perspective. Consequently, many students fail to grasp its broader implications for their future professional practice in the construction industry, which presents them with *troublesome knowledge*. By adopting the pedagogical approach to teaching sustainability that is presented in the current paper, it is argued that students can discover the inter-relatedness of their CO_2 production to that of the construction industry. Further reflection on both creates the opportunity for students to identify boundaries to knowledge and, where they overlap, but importantly, question the concepts to push these boundaries forward. Finally, students will be able to transform their understanding of these concepts to develop a deeper understanding of their contribution to sustainability issues and the importance to the industry. Once these concepts are learnt, they cannot, without great effort, be unlearnt, and so this knowledge and understanding are taken with them into their professional careers.

The sustainability issues regarding the environmental, social, and economic impacts of the construction industry are significant, both in the use of natural resources during the construction process and the resources consumed by buildings (Graham, 2000; Murray and Cotgrove, 2007; Zuo and Zhao, 2014). Indeed, Higham and Thomson (2015, p. 417) argue that "Sustainability represents the UK construction industry's most important and challenging issue." To meet these challenges, construction professionals need to have the necessary skills and knowledge to respond to them (Murray and Cotgrove, 2007; Opoku and Egbu, 2017). The UK Government's industrial strategy of Construction 2025 (HM Government, 2013) has sustainable construction as one of its key objectives, demonstrating the need to improve the environmental performance of the construction industry; thus, making sustainability a foundation in construction education (Murray and Cotgrove, 2007).

Sustainability education for construction and engineering disciplines is critical given the impact their work has on the natural environment and the production of atmospheric CO_2 (Abdul-Wahab et al., 2003), particularly given the importance placed by employers on graduates who are sustainability literate (Opoku and Egbu, 2017). The delivery of sustainability in practice and sustainability literacy, therefore, requires a change in awareness and increased engagement by construction professionals (Higham and Thomson, 2015).

Universities and Sustainability Education

The Agenda 21 action plan, agreed at the 1992 Earth Summit in Brazil, was designed to deliver global sustainable development (Perdan et al., 2000). It recognized environmental education as a critical component in achieving sustainable development (Abdul-Wahab et al., 2003). The importance of education was also recognized in 2003 when The United Nations National Education, Scientific, and Cultural Organisation (UNESCO) declared 2005-2015 their Decade of Education for Sustainable Development (UNESCO, 2003) and identified the crucial role of sustainability in teaching and learning (DuPuis and Ball, 2013; Opoku and Egbu, 2017). The UK Government followed this declaration with its 2005 strategy document Securing the Future: Delivering the UK Sustainability Strategy. In a similar manner to UNESCO, the UK Government's publication declared that sustainability education had a vital role to play in equipping today's generation with the knowledge and ability to pursue sustainable development (Opoku and Egbu, 2017).

As one would expect, universities have become critical players in the delivery of knowledge to produce graduates who can influence sustainability practice to achieve the ambitious internationally-agreed climate change reduction targets (Karatzoglou, 2013; Longhurst et al., 2014; Opoku and Egbu, 2017; Kapitulcinova et al., 2018). It is now widely accepted that much of the responsibility for environment and sustainability education falls to universities (Jones et al., 2008; Segalas et al., 2010; Pappas, 2012). Indeed, Martin and Jucker (2005) argue that the most critical organizations in driving the sustainability agenda forward are universities.

While UNESCO's Decade of Education for Sustainable Development may have called for education to lead the way in developing sustainability knowledge and for it to be fully integrated into all levels of education (Lambrechts et al., 2013), Karatzoglou (2013) posits that universities are vital partners in sustainability education. Higgins and Thomas (2016), however, argue that the position of sustainability education is not as prominent in university curricula as it should be. Jones et al. (2008) have discussed where sustainability sits in higher education curricula, arguing that universities must ensure they provide an educational means by which graduates can meet the many challenges the sustainability agenda presents. Hedden and her associates (Hedden et al., 2017, p. 2) have explained that by offering courses which acknowledge environmental impacts and advance student learning, "universities can affect sustainability education and, thereby, the environmentalist cause."

Notwithstanding the above views that universities do have a pivotal role to play in helping to educate future construction-related practitioners about environmental issues and sustainable development, it is recognized that little has been reported about the most appropriate mechanism by which they should go about undertaking this duty. To help bridge this knowledge gap, the current study suggests that university educators need to rethink their pedagogic approach to teaching and learning: they should adopt the threshold concepts framework as the educational ethos that underpins sustainability education in undergraduate programs in construction.

Constructivism and Active Learning

Piaget (1936) theory of cognitive development was used as the core philosophy of the current study. The theory explains how people construct a mental module of the world in which they live. Constructivism is a learning theory that is founded on cognitive development and explains how people might acquire knowledge and learn from their experience.

Scott and Ghosh (2016) and Hedden et al. (2017) have explained that constructivism can be directly applied to education: students can construct knowledge from experience and then reflect on this experience. An active learning pedagogy was implemented in the current study to empower students with responsibility for their learning (Petty, 2004). The pedagogy encouraged them to interrogate critically a range of alternative options from which to conclude (Deshpande and Salman, 2016). This process embraced the principle of rather than just listening to or reading content, students will learn better by doing and making sense of their ideas (Kapitulcinova et al., 2018). Segalas et al. (2010) have argued that traditional methods of teaching sustainability are inappropriate; they go on to say that students' sustainability knowledge can be enhanced when a constructivist, active learning approach is used. By actively constructing knowledge, rather than just passively acquiring it from their teachers, students can shape their learning (Lee and Hannafin, 2014; Hedden et al., 2017). Hayles and Holdsworth (2008) take this observation one step further by explaining students will develop a deeper understanding of sustainability and its impact on their professional choices when they spend time beforehand focusing on their lifestyle choices.

Threshold Concepts Framework

Providing a lens through which a problem can be considered, the theoretical framework that underpins the current study is the *threshold concepts framework*, which was introduced in 2003 by Erik Meyer and Ray Land. The framework is founded on the observation that there are often concepts presented in university programs that are difficult to understand and, therefore, troublesome to students (Eckerdal et al., 2006). Meyer and Land theorized that this *troublesome knowledge* is often central to the understanding of a discipline (Lucas and Mladenovic, 2007). Despite this, it is considered essential for students to grasp and understand these central concepts so they can move forward in their program and strive for mastery of their subject (Cousin, 2006). Meyer and Land (2003) likened this to the opening of a portal through which previously complex ways of thinking could be accessed and represented a transformation in understanding, enabling a student to progress. They went on to say that once the transition had been made, students would experience phenomena in their discipline differently.

The threshold concepts framework in the context of transformative learning in sustainability education was used during the current study, with the premise that it provides opportunities for students to experience, "a significant shift in the perception of a subject" (Meyer and Land, 2005, p. 373). It is, as Meyer and Land (2005) posit, where critical moments of the educational experience are defined, and students begin to find new ways of understanding their discipline. Meyer and Land (2005) also describe the state of *liminality* as the place a person inhabits as they transition between the different stages of personal development. The "internalization of a concept is likened to a journey or 'rite of passage' within and beyond a liminal space" (Baille et al., 2012, p. 229). It is these liminal states that students find themselves in as they attempt to understand the issues surrounding sustainability.

The five main characteristics shaping the threshold concepts framework are shown below. Each was given a unique code to cross-reference the results.

(1) **Transformative (TRA)**: students make a substantial shift in their perception and understanding of a concept (Lucas and Mladenovic, 2007) and are an essential feature of the framework (Baille et al., 2012). The transformative process enables students to understand concepts within their discipline in a completely different way (Eckerdal et al., 2006).
(2) **Irreversible (IRR)**: once something is learnt, it cannot be unlearnt. Once a concept is genuinely understood, it will take considerable effort to be forgotten. As Baille et al. (2012) identify, gaining an understanding of something in isolation from other things may not be enough to serve one adequately forever. Learning is and should be a continuous process.
(3) **Integrative (INT)**: students discover the inter-relatedness of various phenomena. The inter-connection between concepts, which may have hitherto been hidden, can be exposed to enable students to make a connection between the various concepts.
(4) **Bounded (BOU)**: sometimes described as *boundary markers* (Eckerdal et al., 2006, p. 103), this term describes the boundaries which delimitate a concept. Boundaries can be defined as frontiers of a concept that border with other concepts (Cousin, 2006).
(5) **Troublesome (TRO)**: Eckerdal et al. (2006) describe this term as concepts that are potentially difficult to understand. Meyer and Land (2003) adopted this concept to describe situations where students struggled to comprehend concepts within their discipline. By tackling the relationship between theoretical knowledge and the context in which it is applied, then by reflecting upon their experience, students can step across the threshold of knowledge and develop a deeper understanding of their discipline.

RESEARCH METHOD

Carbon Calculator

During the current study, the *carbon calculator* was the teaching tool used to help students to acquire an understanding of the environmental and sustainable development issues faced by the industry in which they will work as graduates and professionals. The carbon calculator is an online tool designed to measure a person's CO_2 footprint. The reasons behind the decision to use the tool were twofold. First, it allows students to calculate and understand their carbon footprint. By doing so, students gain a deeper appreciation of their individual lifestyle choices and how these influence their overall result in terms of its contribution to rising atmospheric carbon concentration. Second, it provides an easily accessible education tool from which students can extrapolate and translate their lifestyle choices and behaviors affecting CO_2 production into their future careers as professionals working in the construction industry. As a result of doing this, students can relate the outcomes of their carbon calculation to the construction process; hence, assisting them with their understanding of the challenges faced by the construction industry in the real world.

A final year undergraduate construction technology course was chosen as the setting for the current study. This decision was taken because the course was well-established and was not highlighted for significant learning and teaching revisions in the medium- to long-term. Also, a large proportion of the syllabus focuses on sustainability and construction technologies and how they impact on buildings in their final use. As part of the course, students are introduced to a freely accessible online tool to input data about their lifestyle choices and behavior, including data relating to their energy bills, travel arrangements, shopping habits, and household. The carbon calculator tool can be accessed from http://www.carbonfootprint.com/calculator.aspx.

Students were asked to complete the exercise several times (based on different situations) to ensure they had enough data to compare. Examples of different situations the students could use included living at their parental home, living away from home while studying at university, and where relevant, living away from home and university while completing a year-long professional practice placement. The online carbon calculator tool was introduced to students in a seminar during which the stages in the calculation process was explained and demonstrated. The step-by-step process allowed students to take note of the different types of information they would need to capture to complete the calculation. Each student was then asked to gather his or her personal, relevant information and to complete the online exercise within three weeks (see **Figures 1**, **2**). As part of the task, the students were asked to present their results, offer a discussion and comparison of their data, and relate their conclusions to the construction industry about how their results may influence their approaches to the construction process. The final stage in the exercise required students to reflect upon their findings and consider whether they had increased their understanding of sustainability issues, if their experience had influenced their thinking in the broader topic area, and more specifically, had it shaped their future attitude toward dealing with sustainability in the workplace.

CONTENT ANALYSIS

Content analysis is a research technique for the objective, systematic, and quantitative description of the manifest content of communication (Berelson, 1952, p. 18). Hsieh and Shannon (2005), Elo et al. (2014), and Bryman (2016) have explained it is a flexible technique that can be applied to a variety of different media but is predominantly used to analyze text. Large quantities of text can be studied using content analysis, ranging from the simple counting of words to generate word frequencies (Bryman, 2016), to coding and the detailed correlational examination of language (Weber, 1990), and finally, to classification and categorization of themes to provide a comprehension of the phenomenon of the study (Downe-Wambolot, 1992).

Content analysis of the past four years of portfolios submitted by 136 students completing a final year construction technology project was undertaken using NVivo 11 Pro. The analysis started with a word frequency query and progressed to a text search query of keywords and labels associated with environmental issues, sustainable development, and construction. The written reflections of the students contained in the portfolios were also classified and categorized to key themes identified from the extant literature to provide a structure to the focus of the current study.

NVivo provides functionality to improve the meaningfulness of word frequency and text search queries with *stop words*. These include words associated with definite and indefinite articles, conjunctions, and prepositions. Additional study-specific stop words were added to the list, including those used in the carbon calculator, and abbreviations such as US, UK, EU, CO_2, etc. The results across all four academic years were then collated and ranked in order from the most to the least frequently occurring. When collating the results, stemmed words were grouped to retain their distinctiveness, but synonyms, specializations, and generalizations were kept separate.

RESULTS

The count of the top 10 results was presented using pivot charts in Microsoft Office Excel and is illustrated in **Figure 3** below.

Of all the study-specific words cited by students in the reflective commentaries, 'building' topped the list with a count of 2,345. This result contrasts with 'products' with a count of 495. When the word frequency list was broken down into two broad categories according to the bifurcated nature of construction, i.e., *process* and *product*, it was noticed the list was divided between the two with a ratio of 5:5. Although simple in method, the result illustrates the propensity of the students to recognize the implications and application of sustainability issues to both the physical product arising from the construction process and the nature of the construction process itself.

During the initial coding of the qualitative data, several themes began to emerge. Further coding distilled these into the following four central themes: sustainability as a theoretical topic, Carbon Calculator as an online tool, connecting learning to the construction industry, and career development.

Sustainability as a Theoretical Topic

The principle tenet in the current study is that many students view sustainability as just another theoretical concept they are required to study without fully appreciating its relevance to the construction industry. Results arising from the qualitative analysis of student portfolios appear to support this viewpoint. Many students expressed surprise at the implications their lifestyle choices had upon their carbon footprint and the subsequent ramifications for the construction industry concerning its contribution to atmospheric carbon. In other words, constructivism and the use of an active learning approach enabled the students to become enlightened about the impact construction activity has on the natural environment. By way of example, many students cited how their lack of understanding

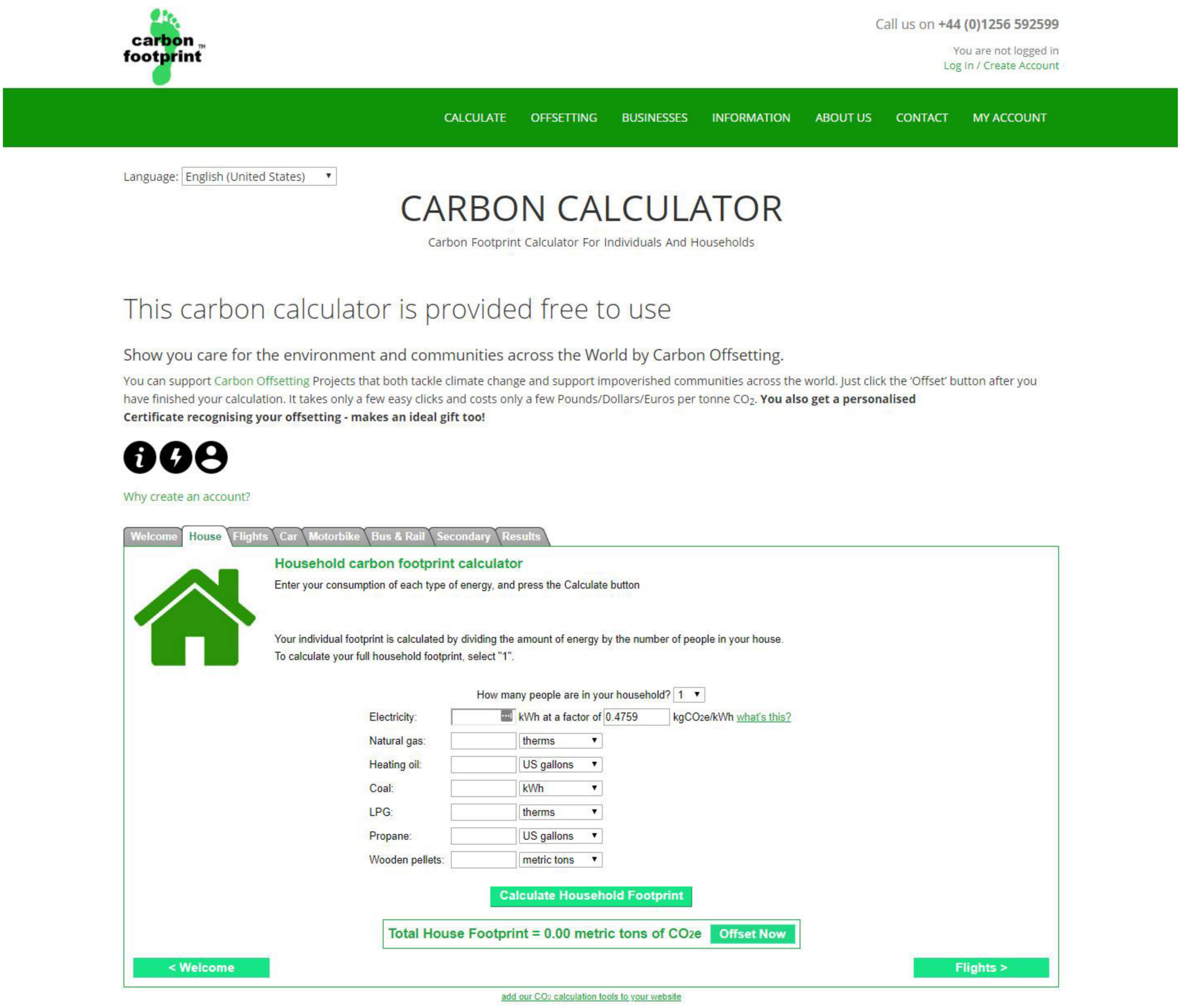


FIGURE 1 | Household carbon footprint calculator data entry page.

and awareness of the impact buildings have on the environment had changed following their work using the carbon calculator.

> "*[...] has shown me how important sustainability is in construction – the issues will not disappear.*"

> "*I can now see how construction plays a major part in the UK's carbon footprint.*"

> "*I would not have understood or considered the issue of sustainability were it not for the module.*"

Many people see construction as an industry dominated by cost and profit; therefore, it was interesting to read comments where cost and profit were discussed in the context of sustainability. One student suggested that profitable businesses can also be sustainable.

> "*I can now see the construction industry not just as a profitable business but also, potentially one day, a completely sustainable industry.*"

While others acknowledged the importance of *client buy-in* to sustainability recognizing that:

> "*[...] clients need to understand that although some technologies have a high initial cost, they could reduce expenditure for them in the future.*"

> "*[...] before I did not have an appreciation of the true value of whole-life costs.*"

> "*The module and assessment have made me aware of the environmental and economic costs of sourcing raw materials, manufacturing and delivery.*"

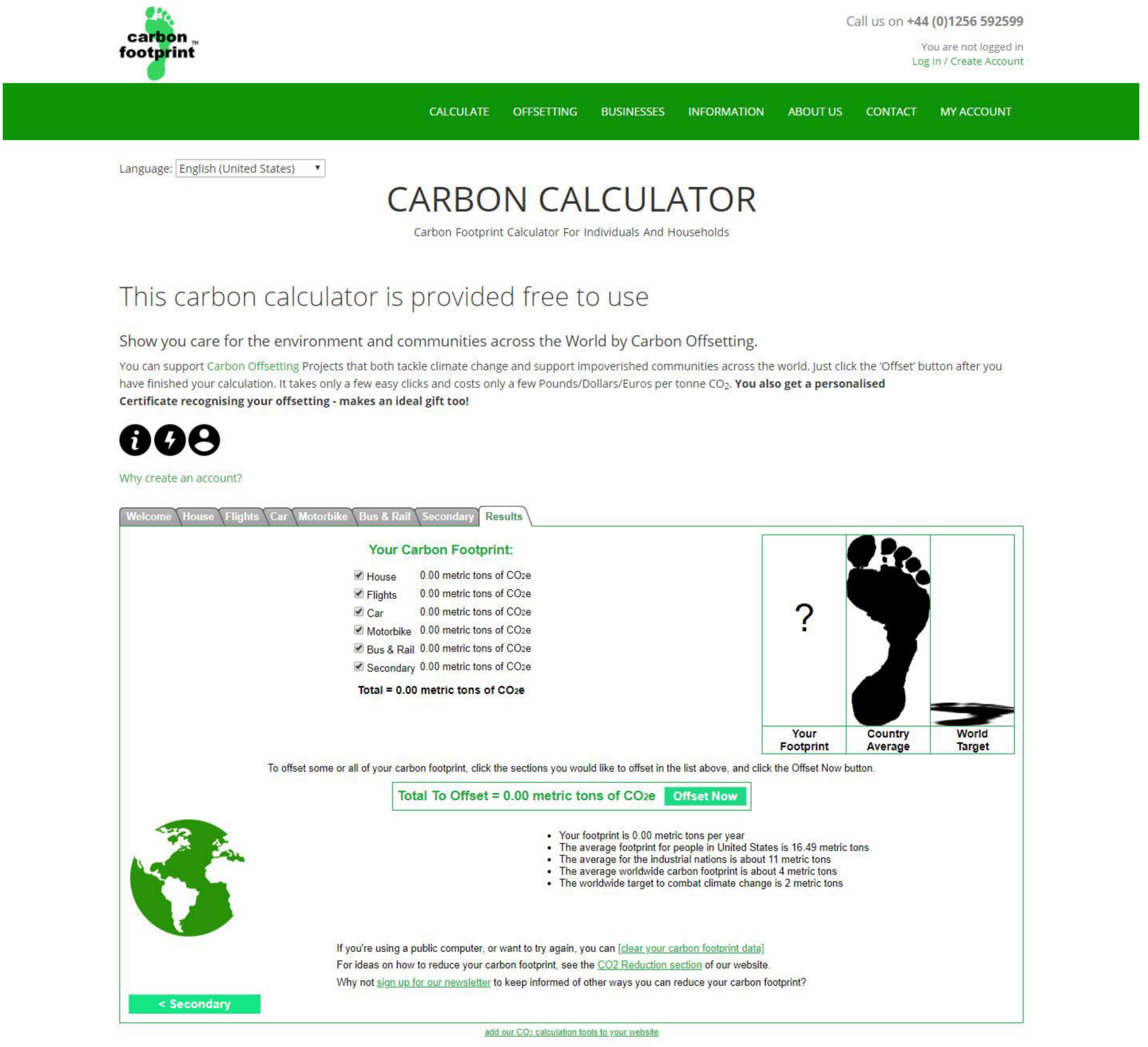


FIGURE 2 | Your carbon footprint results page.

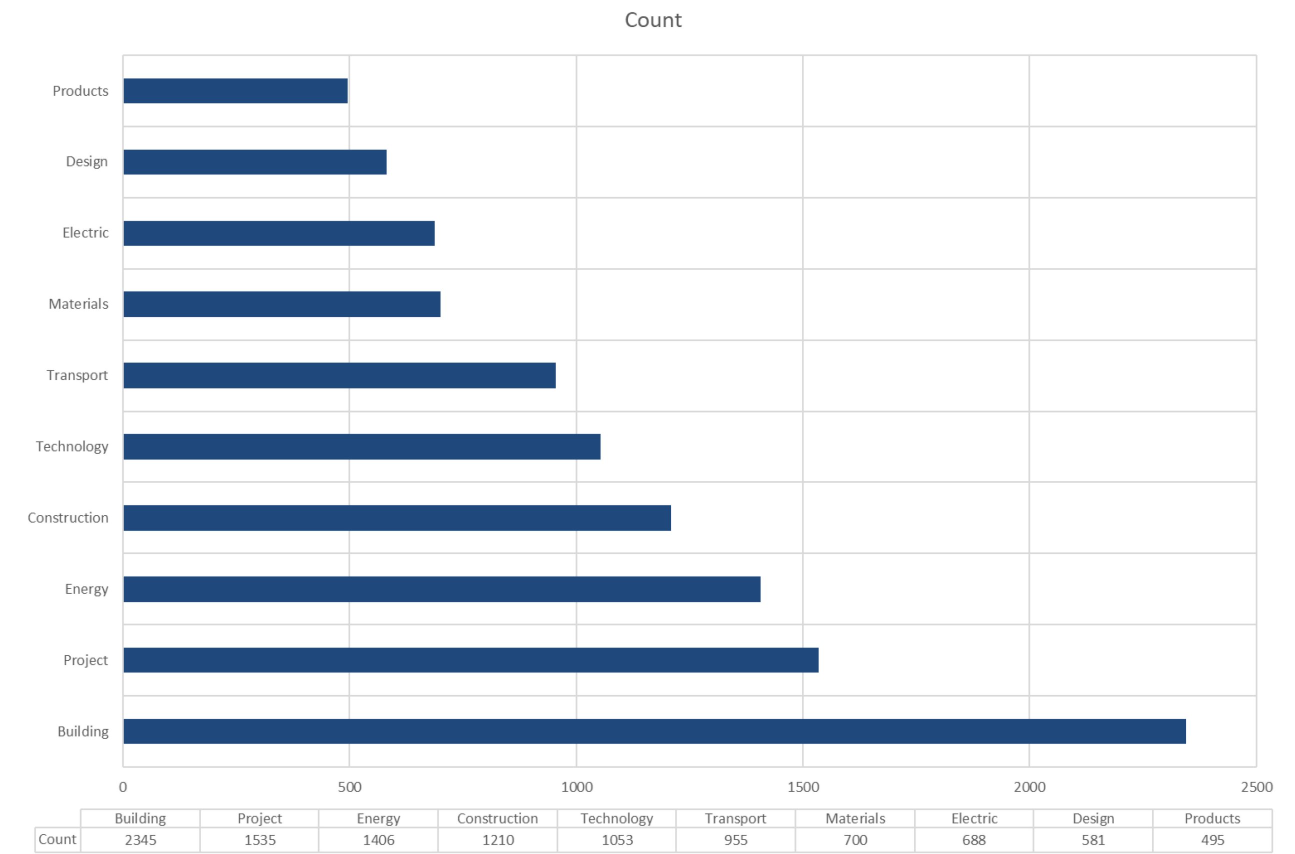
Although sustainability has been a discussion point for many years among the public, politicians, and academics, the first real significant global addressing of the issue was the Brundtland Report (World Commission for Environment and Development, 1987), followed in 1992 by the Kyoto Protocol (United Nations, 1997). Since then, sustainability has grown in prominence, particularly in the construction industry. Despite this rich history, there was a distinct lack of awareness among students of sustainability being a real-world issue for the construction industry. The following comments from two students highlight this viewpoint and support the author's position that sustainability in construction education has been reduced to a theoretical concept to the point that students are unaware of the critical position it occupies.

"*This module has opened my eyes to the industry's significant contribution to climate change.*"

"*Sustainability, I feel, is something that has not been talked enough about in industry in the past: it is not something you focus on while on site.*"

CARBON CALCULATOR AS AN ONLINE TOOL

The use of the carbon calculator as an online tool for active learning proved useful in highlighting the issues around CO_2 production and provided a catalyst for the students to explore this in more detail.



	Building	Project	Energy	Construction	Technology	Transport	Materials	Electric	Design	Products
Count	2345	1535	1406	1210	1053	955	700	688	581	495

FIGURE 3 | Number of citations in student portfolios of construction terms.

"By analyzing our personal [stet] use of carbon, we can understand the enormity of the task faced by all industries in tackling the sustainable agenda."

"I feel that the use of a carbon calculator [. . .] has been very enlightening to me."

"The carbon calculator [. . .] makes you realize what the most carbon-intensive areas are."

The first step of using the carbon calculator in the assessment helped students to start to challenge current practice and look for alternative environmental options when producing buildings. Throughout the exercise, use of the carbon calculator also allowed the students to develop essential employability skills, such as problem-solving and critical analysis skills, and, as a result, they began to challenge their baseline thinking.

"I have learnt to challenge and critically evaluate the technologies and materials used in construction projects and understand their contribution to the environmental performance and sustainability of the building."

"By improving my knowledge of these areas, and modern sustainable technologies and materials, the module has allowed me to challenge the norm and the current methods used in the industry."

"The assessment has helped me to understand and be able to appraise construction technologies critically."

The assessment was explicitly designed to offer an alternative pedagogical approach to improving student' sustainability literacy in the context of the construction industry. It is worth noting how the carbon calculator exercise had an impact on students and encouraged them to look at ways of reducing their carbon footprint.

"During analysis of my carbon calculator results, it became evident that I must strive to improve certain areas of my lifestyle to live more sustainably."

"By being aware of the impact my daily actions have on the environment, and by making small changes to my lifestyle, I can see it is possible to have a smaller carbon footprint to help save the environment."

"[.] the module has given me an appreciation of how my actions can influence the production of carbon emission. In the past, I did not recycle, but now recycling is a part of my day-to-day life."

"When I think back to my carbon calculator results, I can see the impact recycling materials and changes to my lifestyle choices will help to offset my carbon footprint."

One part-time student, on receiving the results of her carbon footprint, said, "This has shocked me!" She was so taken aback with the thought-provoking results the carbon calculator produced; she encouraged work colleagues to complete it and to think about their carbon footprint.

"*As I was surprised at my carbon calculator results, I thought I would survey five operatives on site to see what their carbon footprint was. Four out of the five had a carbon footprint higher than the UK average. Generally, they were all shocked at their level of CO_2 they produced.*"

The pedagogic approach to active learning using the carbon calculator provided students with a distinctive opportunity to experience real-world phenomena differently. By placing the focus on their lifestyles, they developed a deeper understanding of CO_2 production, causing a significant shift in their perception of the issues and, thereby, developing their sustainability literacy.

Connecting Learning to the Construction Industry

Having introduced the concept of CO_2 production by focusing on their lifestyle choices, students, in the next stage of the assessment, were asked to reflect on their experience and use their learning to develop an understanding of how their choices could be extrapolated to the construction industry. The purpose of this stage was to encourage the students to apply their newly acquired sustainability literacy elsewhere. The results showed the students were able to demonstrate their transformative experience from one contextual setting to another and see the inter-connectedness of their sustainability literacy to other program areas.

"*When I reflect on my knowledge acquired from the carbon calculator, my results influenced the environmental choices, technologies, and materials I have used in my building project assessment.*"

"*I used my carbon calculator results to analyze the technologies in the buildings to understand their sustainable credentials; this influenced my design choices for my professional practice project.*"

Students also began to focus on specific construction-related issues, such as materials choice, with a recognition that the embodied energy, particularly CO_2 production, can have a significant impact on product selection and building technology options.

"*[.] informed decisions about the specification of materials are needed with consideration given to the environmental impact of the materials; namely, the embodied energy they contain.*"

"*The module and assessment have made me aware of the environmental and economic costs of sourcing raw materials, manufacturing, and delivery.*"

"*It has given me the knowledge to influence the building design to source sustainable materials and bring new technologies to a project to reduce carbon emissions.*"

There was also a recognition by students that all stakeholders involved in the construction process have a responsibility to address sustainability issues in the industry.

"*The design and planning of a new building should consider the costs to the environment and what are the most energy-effective materials to use in the building.*"

"*There is often a conflict of interest between the parties interested in a new building. The bottom line involves balancing the building cost with the performance of the building while considering the payback in value/rental terms for the owners/financiers.*"

"*I now understand that it is important to consider the lifespan of a building and how an upfront investment in materials and technologies can benefit the environment and stakeholders in the long run.*"

One area to feature prominently in student reflections, as a direct result of the carbon calculator exercise, was recycling and waste management. Students recognized this was a key aspect of on-site construction practice and thereby considered its significance regarding good site management.

"*[. . .] within the industry, we still factor in a degree of waste that we just accept as the norm.*"

"*If I could have any influence on the building project from my results, I feel that one of the focuses should be on the strategic and proper waste management of materials on site.*"

"*Not just in construction, but in the UK, we need to think about re-using buildings and materials, be that refurbishing buildings or recycling building materials.*"

"*Currently, within the construction industry, we still factor in a degree of waste that we just accept as the norm. We need to change this way of thinking massively.*"

One section of the carbon calculator focuses on personal energy use. Many students were able to relate their experience of this aspect of their carbon calculation to the energy performance of buildings.

"*The carbon footprint calculator exercise helped me to identify that one of the most sensitive areas of decision making is the energy consumption from the building.*"

"*The results enabled me to identify the energy performance issues which affect the energy efficiency of the building and identify methods and assessment tools that can be used to improve building energy performance.*"

Most notably, one part-time student reflected on his company's practice in this area to improve the energy efficiency and performance of the buildings it built.

"*I aim to take the progress my employer has made into schemes by aiming to exceed the BREEAM target of 'very good' to achieve an 'excellent' rating.*"

The qualitative analysis of student reflections highlights how they have successfully translated their carbon calculator results to address specific construction-related issues. There is an explicit recognition of the environmental issues currently facing the construction industry and where it needs to focus its attention in order to address them. As future construction managers, the students were able to consider the importance of responsible construction site management practice to the everyday operational issues with which they will be expected to address in their future professional lives. There is now, however, a greater appreciation of broader issues such as design for energy efficiency and materials specification. These may be areas in which students have limited influence, but armed with their increased sustainability literacy, they can make a significant contribution to addressing the environmental issues they will face as future construction professionals.

Career Development

The literature on sustainability education identifies the importance of future construction professionals having the necessary sustainability literacy to tackle the environmental challenges facing the construction industry (Hedden et al., 2017; Murray and Cotgrove, 2007; Opoku and Egbu, 2017). Bearing this in mind, the final part of the assessment asked students to discuss how they could apply their newly acquired sustainability knowledge in their future careers as construction managers.

When equipped with current knowledge and understanding, the students were able to recognize the importance of sharing their knowledge to educate others, which was pleasing to see. Just as the part-time student referred to above encouraged her co-workers to calculate and address their carbon footprint, future sustainability literate construction managers can also influence the practice of others and help them support the environmental challenges faced by the industry.

> "*[. . .] with this knowledge, the industry can deliver projects that meet clients' requirements, advise on environmental issues, educate others, and contribute to sustainable construction.*"

> "There is a need for the teaching of sustainable technologies and materials to educate up-and-coming site managers with the knowledge to be able to have an impact on the environment."

> "*[. . .] site managers require the knowledge to be able to have an impact on the environment.*"

Decision making is a crucial skill for a construction manager. It was interesting to observe how students recognized their sustainability literacy would allow them to make informed decisions in the future when undertaking a site management role, and how it would be informed by their participation in an active learning scenario.

> "*When I start working in the construction industry, I will be able to make informed decisions when I speak with the client to make recommendations.*"

> "*I feel that the portfolio has given me the opportunity to become a well-informed construction professional of the future who can make a positive impact on the environment.*"

There was an explicit acknowledgment among the students of the sustainability challenges faced by the construction industry and a recognition that the industry cannot carry on in the manner to which it has become accustomed.

> "*It is important to re-think what they are doing as far as sustainability is concerned – rather than continuing to do traditional methods of work in unsustainable ways.*"

> "*If I do not increase my knowledge and understanding of the main sustainability issues, I am likely just to follow traditional construction methods.*"

Having realized that the industry faces real challenges to address the pressures placed on the natural environment because of unprecedented CO_2 production levels, students acknowledged that their learning and understanding of sustainability had adequately prepared them to face these problems when entering the industry as graduate construction managers.

> "*The assessment has helped me to understand and be able to critically appraise construction technologies so that in my future career, I will have an appreciation of environmental performance issues and how technology can influence and overcome these issues.*"

> "*I now feel much more educated, confident, and excited to get out into the industry and put these techniques into practice.*"

> "*As a future graduate going out into the construction industry, this module has prepared me for future changes in legislation and government regulations.*"

CONCLUSION AND DISCUSSION

This paper has described an innovative pedagogic approach to sustainability education that was used with final year undergraduate construction students over four years. Using an active learning, constructivist approach to teaching and learning, as advocated by Segalas et al. (2010) and Lee and Hannafin (2014), the assessment method used by the researchers narrowed the focus of the students' learning to lifestyle choices and their implications for potential CO_2 production. By doing so, the approach enabled the students to develop a deeper understanding of sustainability issues, as stated by Hayles and Holdsworth (2008). Incorporating the coded characteristics of the theoretical framework, the following conclusions have been drawn.

The students' thoughtful accounts of their carbon calculator results encouraged them, when prompted, to reflect upon the outcomes of the exercise and to extrapolate and apply their findings to their future careers as construction managers. The carbon calculator exercise enabled students to realize the importance of sustainability within the construction industry and the need for more action to be taken (TRA). The students' qualitative reflections confirmed the success of the current study in demonstrating the purported benefits of adopting an active learning pedagogy to sustainability education, as reported by Petty (2004) and Dee Fink (2007). The assessment method was designed to reinforce the students' learning and encourage them to think about the sustainability challenges faced by the industry to which they would soon be entering as a new graduate. It is argued that this learning is irreversible (IRR): graduates can use it as their career progresses. What may have appeared troublesome (TRO) for students to understand from a theoretical perspective became clearer when the concept was linked to their circumstances and applied to the industry. What is clear from the analysis is that the carbon calculator exercise proved to be a significant catalyst in enhancing the sustainability education of students and improving their sustainability literacy (TRA), which is evidenced by the work of Deshpande and Salman (2016).

The construction industry has been described by Wood and Ellis (2005) and Burtonshaw-Gunn (2016) as a cost-driven industry. Students recognized the importance of sustainability in both the construction process and its product; thus, breaking through the financial boundaries of construction by acknowledging there is a place in industry for both (BOU).

Reflection is an essential stage in meaningful learning. Students were encouraged to reflect on what they had learnt at each stage of the assessment process, as identified by Kapitulcinova et al. (2018). There was much surprise and, in some cases, shock at how the students' carbon footprint compared to that of the UK average, with some students vowing to make significant lifestyle changes to transform their approach to sustainable practices and reduce their contribution to global CO_2 levels (TRA). The authors of this paper suggest the result is symptomatic of the current situation and confirms the external validity associated with the adoption of a constructivist, active learning approach to the sustainability education of construction professionals at a university. The method enabled students to understand their contribution to environmental issues and feedforward the outcomes of their learning and experience to their future careers (INT).

The primary aim of the current study was to encourage students to develop a deeper understanding of the environmental challenges faced by the construction industry and, as future construction professionals, recognize their place in addressing them. Key results from this study are as follows:

(1) a realization that sustainability is not a theoretical topic to be studied at university but a real-world problem that must be recognized and addressed (INT);
(2) provide a more precise understanding of the impact the industry has on the environment (TRA);
(3) acknowledgment by students that there are challenges faced by the industry, and these challenges are real, and they will bear some responsibility to address them (BOU/INT);
(4) a recognition that the students' learning has equipped them with the knowledge and literacy to meet these challenges and influence the way the industry impacts on the environment (IRR);
(5) by focusing first on a student's personal lifestyle choices, learning can be reinforced, and a deeper understanding of sustainability can be achieved as a result (IRR); and
(6) a demonstration that a constructivist, active learning approach to sustainability education can create a successful and effective student learning experience (TRA).

It is acknowledged that students, as future construction-related professionals, need to understand and recognize that sustainability is a real-world issue. The current study has demonstrated the significant and problematic nature of sustainability literacy being taught purely from a theoretical perspective. The headline statistics are a grim reminder of the potential implications for the natural environment if universities remain static in their use of pedagogic approaches to support sustainability education. The current study reveals the potential impact universities can make to the natural environment by supporting the construction industry in its drive to reduce harmful CO_2 emissions by changing to a constructivist, active learning pedagogy for sustainability education. The approach enables construction students to link their environmental attitudes and behaviors to the broader environmental issues faced by the construction industry.

As UNESCO and the UK Government have stated, sustainability education and literacy are vital to meeting targets set by international agreements in order to reduce carbon emissions. The learning, teaching, and assessment strategies used by universities need to recognize that if students are to tackle the challenges they face when entering the industry, pedagogic approaches need to focus on environmental lifestyle choices and reflection to reinforce their learning and future application as a construction professional.

Recommendations

The following recommendations, which have emerged from the findings of the current study, enumerate what universities, as providers of construction-related courses, and construction industry stakeholders should consider:

(1) survey construction graduates to establish the extent to which their sustainability literacy now influences their professional practice;
(2) recognition that the sustainability issues highlighted in this research are not limited to the UK but are global issues. As such, there is much scope to extend this pedagogic approach to universities and sustainability education around the world;
(3) further research is being undertaken that will evaluate the attitudes to sustainability of EU and non-EU university students;
(4) revisit how sustainability is delivered across construction curricula and examine if the approach adopted in the current study can be used in other construction-related disciplines;
(5) consult with professional, statutory, and regulatory bodies (PSRB) to embed sustainability within their processes for the accreditation of programs not just as a knowledge base but as a graduate attribute which can benefit the construction industry;
(6) encourage external stakeholders, including employers and PSRBs, to develop continuing professional development training packages in sustainability that will promote a similar approach to active learning for those construction industry professionals who were not educated using this pedagogy.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Northumbria University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

JW and AO conceived the original idea, discussed the results, and contributed to the final version of the manuscript. JW developed the introductory and theoretical framework sections. AO designed and carried out the data analysis.

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