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Sustainability in Web Development through Energy Efficiency

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Honors Project

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Abstract

As global internet usage expands, websites are growing in both size and complexity. Contrary to the common belief that the internet is immaterial and "environmentally friendly", web pages have significant negative environmental impacts (Frick, 2015). Websites contribute to global greenhouse gas (GHG) emissions and electricity consumption. Considering the current climate crisis, it is crucial that web developers be aware of the impact that their work has on the environment and actively work to improve site energy efficiency. With a lack of regulation and awareness, the environmental impact of websites has remained unchecked despite growing concerns for sustainability. Further research and awareness is needed in the area of sustainability in relation to the digital world, specifically within web development. This applied research project aims to identify best practices for sustainable web development that can reduce GHG emissions by improving site energy efficiency. The resulting methods were applied to the development of two versions of a website in collaboration with a community partner. To understand the implications of sustainable development, data from both versions was collected on CO2 emissions, energy consumption, and energy efficiency. Version two with the sustainable development methods resulted in reduced CO2 emissions and increased energy efficiency.

Keywords: Sustainability, Web Development, Visual Communication Technology, Internet, Front-End Development, Energy Efficiency, Environmental Impact, Interactive Media, Greenhouse Gas

Research Question

How can front-end web developers build websites that are energy efficient and environmentally friendly?

Additional Research Question: Can a development case study justify the effectiveness of sustainable best practices?

Key Terms

Sustainability - “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987).

Green Hosting - Web hosting that is powered at least partially by renewable energy or that offsets carbon emissions through environmentally friendly initiatives.

Introduction

The internet is considered to be an intangible, immaterial service that is available anytime from anywhere. This contributes to the common perception that the internet is environmentally friendly and without negative impacts. The connection between viewing an individual website and the resulting environmental impact is not frequently considered. As a simple explanation, all websites live on servers, which can be privately owned or powered by huge data centers. These data centers require large quantities of electricity to power all of the servers. While some “Green Hosts” receive power from renewable energy sources, the majority of web hosts and data centers are powered by energy from fossil fuels. A survey of industry professionals predicted that 79%

of data centers will still be powered by fossil fuels in the year 2025 (Cevenini, 2019). This leaves the percentage of renewable energy in the digital world at a minority.

In response to growing concerns about the environmental impact of the digital world, a new branch of Information Technology arose, Green IT. While this industry typically focuses more on technology hardware, the available research is still applicable to web development. A French report on the environmental footprint of the digital world revealed that 3.8% of all global GHG emissions from 2019 stemmed from these technologies (Bordage, 2019). 3.8% may not seem significant but this equates to 1.4 billion tonnes of GHG from the digital world alone. While the digital world encompasses more than just websites, the internet is a significant part of the category. The report also revealed that the digital world required 6,800 TWh of primary energy that year (Bordage, 2019). These insights reveal that there is much room for improvement and work to be done to lower the environmental impact of the internet and websites.

Review of the Literature

As a relatively newer field of study, sustainability in relation to web development is somewhat limited when it comes to academic, peer-reviewed research. Much of the available academic literature focuses on programming and the impact of the entire software development lifecycle. While these sources may not be directly applicable to web development, they provide key insights into the environmental impact of the digital world and general principles that can be applied to front-end development. In a study on the efficiency of various programming languages, the key insight that different scripting languages impact electricity consumption and computer readability is significant (Pereira, 2021). While this study was intended for back-end software programming, the results apply to front-end development by revealing that there is a

connection between a site's code and energy efficiency. Another research study on the analysis of the software development life cycle (SDLC) revealed that sustainable methods exist and can be implemented into every area of the SDLC process. The authors also concluded that there is a problematic lack of energy monitoring tools for the digital world (Georgiou, 2019).

Gray literature is much more widely available for this topic. In his book *Designing for Sustainability: A Guide to Building Greener Digital Products and Services*, author Tim Frick discusses the significance of a sustainable digital world and why it is important to consider. He discusses related policies and recommended changes to be adopted by the development community. Tim also proposes a framework to improve web design sustainability (Frick, 2016). This framework influenced the methodology and development process of this project. Wholegrain Digital is another leading company in sustainable web development. Numerous blog posts on their company site delve into specific ways that front-end developers can improve the energy efficiency and sustainability of their work (Greenwood, 2019). Tom's book *Sustainable Web Design* provides additional tangible methods for sustainable web development (Greenwood, 2021). Gray literature and web sources on the topic of sustainable development are abundant and continuing to gain traction as the lesser known field receives more awareness.

Review of the Literature - Annotated Bibliography

The following literature informed this research and provided background information on the environmental impact of the digital world:

Georgiou, Stefanos, Stamatia Rizou, and Diomidis Spinellis. "Software Development Lifecycle for Energy Efficiency: Techniques and Tools." ACM Computing Surveys, vol. 52, no. 4, 2019;2020;, pp. 1-33.

Georgiou, Stefanos, Stamatia Rizou, and Diomidis take a deep dive into the software development life cycle (SDLC) from the very beginning stages to post-development. By thoroughly reviewing each step in the development process, and compiling research results, the authors are able to determine several practical ways to improve software energy efficiency. When used in combination, the suggested methods can drastically reduce software energy consumption.

Georgiou et al. recommend best practices for the following SDLC stages; requirements, design, implementation, verification, and maintenance. The research compiled is an attempt to provide a holistic overview of energy consumption which is becoming an increasingly important issue. This article compares and examines a wide variety of tools, techniques, and design flows to determine practical ways to reduce device energy consumption.

This text is beneficial to the research being conducted because some of the information included is applicable to front-end web developers. This article discusses programming languages, design patterns, industry tools, and GreenIT methods that can be implemented by web developers to lower energy consumption. The holistic approach gives a broad overview of the topic and recommends specific actions software engineers can take at every stage of development.

Murugesan, San, and G. R. Gangadharan, editors. Harnessing Green It. John Wiley & Sons, Ltd, 2012. https://ebooks-ohiolink-edu.ezproxy.bgsu.edu, doi:10.1002/9781118305393.

This book gives an in depth explanation of the practices, policies, and history of the Green IT industry. Referring to Green IT as "[the] study and practice of designing, manufacturing and using computers, servers, monitors, printers, storage devices and networking and communications systems efficiently and effectively, with zero or minimal impact on the environment", the authors emphasize the importance on the new sustainable role that IT has to play. By looking at the entire lifecycle of computers and IT hardware, the authors are able to recognize weaknesses.

Some of the environmental issues relating to computer technologies mentioned in chapter 1 of this book include; rising greenhouse gasses (GHGs), electricity consumption, e-waste, and toxic material. This book gives a variety of specific statistics on energy

consumption as well as suggestions for individuals and enterprises to shift to a more sustainable model of information technology.

This book will be very beneficial to the research because it is a good overview of key terms that are used in other higher level journal articles. The authors go beyond explaining the environmental issues that stem from IT by providing moral arguments for becoming more sustainable. This will add a great perspective and layer to the research I am conducting. While this book is directed towards Information Technology, many chapters discuss software development and the topic as a whole is related to the research question.

Pereira, Rui, et al. "Ranking Programming Languages by Energy Efficiency." Science of Computer Programming, vol. 205, 2021, pp. 102609.

This research study aimed to determine the most efficient programming languages in an array of situations. The authors defined efficiency in two different ways; consuming the least amount of energy, and speed. In doing so, the researchers were able to determine the highest and lowest ranking languages for different scenarios. Across the board, the C programming language performed the highest consistently, making it the most energy efficient and fastest language. Python and Java were consistently among the lowest performing languages.

The authors also debunked the common misconception that a faster running program equates to lower energy consumption with data evidence. Considering that this is a further study done to expand on past research, the authors have very detailed methodology with visuals to help explain everything. The study is based on five essential questions with the goal to get a clear picture of energy efficiency in common programming languages. All of the data is based on clear computer benchmarks.

This study is very relevant to the research being conducted and can provide strong suggestions for software developers aiming to create more sustainable programs and websites.

Procaccianti, Giuseppe, Héctor Fernández, and Patricia Lago. "Empirical Evaluation of Two Best Practices for Energy-Efficient Software Development." The Journal of Systems and Software, vol. 117, no. July 2016, 2016, pp. 185-198.

Giuseppe et al. have developed an original research study to determine the impact of two different proposed software energy saving techniques. The two practices studied were using efficient queries and putting the application(s) to sleep. Results conclude that both methods successfully lowered energy consumption of the test devices. The authors emphasize the rising importance of green software as the industry continues to rapidly expand. They emphasize that the suggested practices not only improve energy efficiency but they also showed performance improvements. This article discusses the energy impact of cloud computing which is quickly becoming increasingly popular. The cloud

computing process is very energy intensive and the authors recognize that energy efficiency in these programs is essential.

This article is beneficial to the research because it provides a very broken down, overview definition of green software. It also includes original research with practical methods that can help software engineers develop more energy efficient software. The research methodology is thorough and clearly documented. The source also includes many references to other research papers that will be helpful for further research.

Tseng, Hsueh-Wen, et al. "An Energy Efficient VM Management Scheme with Power-Law Characteristic in Video Streaming Data Centers." IEEE Transactions on Parallel and Distributed Systems, vol. 29, no. 2, 2018, pp. 297-311.

Videos and video streaming is a huge part of many websites. While some videos are embedded in the actual structure of the site, cloud computing allows the videos to be stored elsewhere (Youtube for example) and recalled when interacted with. This study explores the energy consumption of cloud computing in relation to videos. The authors explain video traffic distribution and how it can vary, causing spikes and valleys in energy consumption.

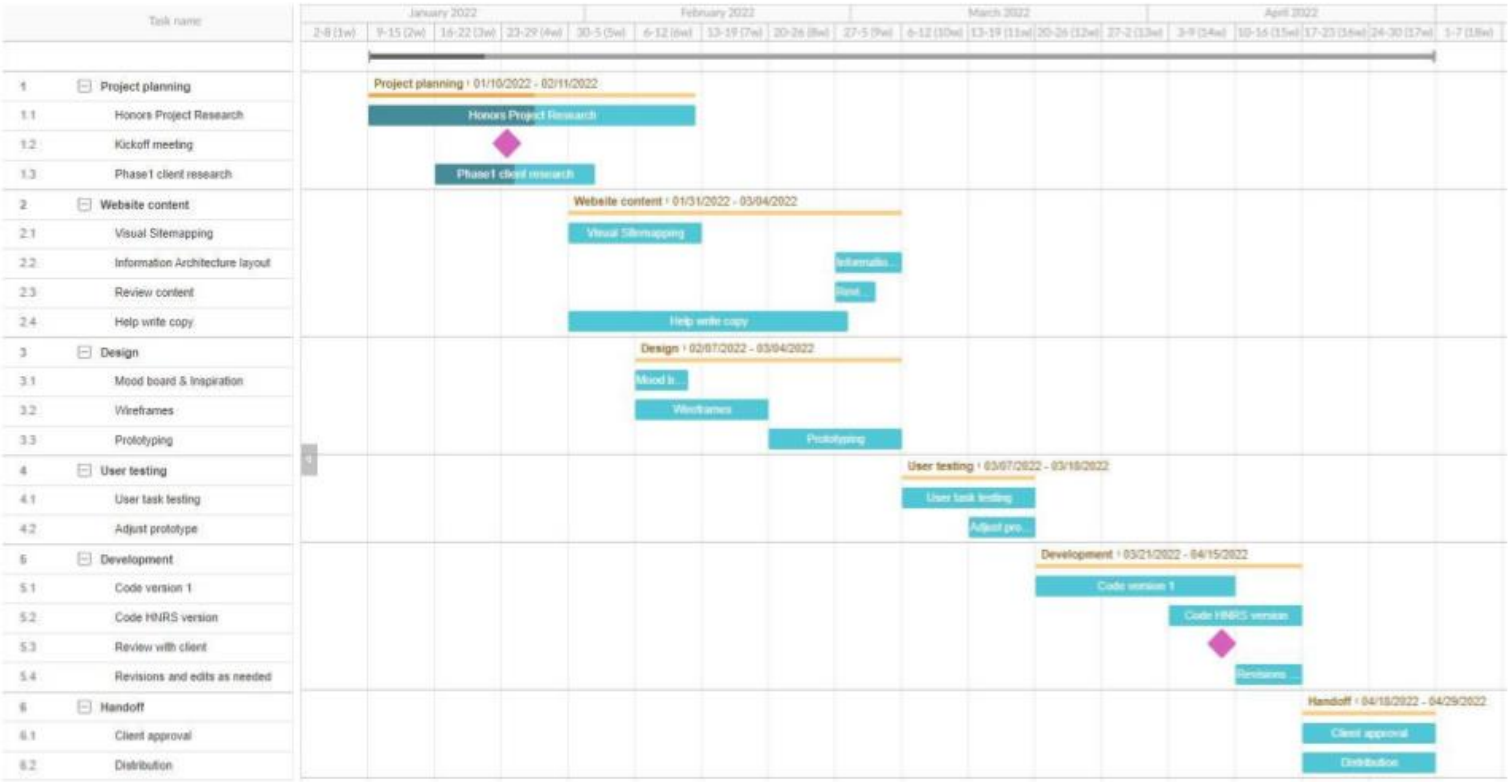
In evaluating the methodology of this study, one drawback is that the conclusions are based on a simulation of the Youtube algorithm. As is the nature of internet videos, different topics are trending at different times. This could potentially have a significant

impact on the simulation data that was used in the study. That being said, the article still contains helpful information on video streaming and cloud computing. This article also discusses the environmental impact of video transcoding. This would be insightful to include in my research as a different aspect of web development.

Methodology

Project Overview

The completion of this semester-long research project was divided into 4 different stages: collaboration, research, development, and testing. The following Gantt chart reflects the project timeline for research and development of the test sites and was used to stay on track with project deadlines:



Collaboration:

HNRS 4990 was completed in conjunction with VCT 4670 at Bowling Green State University. As a requirement of VCT 4670, a website was developed in collaboration with community partner, TNT Retreats, LLC (upcoming short-term vacation rental company) in order to solve a visual communication problem. This company's visual communication problem involved a lack of a way to communicate their property amenities and descriptions to potential renters through a website. Phase documents were created throughout the semester within the VCT 4670 class to document the entire company analysis and design process. While the site used for this project was developed for a specific business, the methods and conclusions can apply to any site.

Research:

In order to understand the environmental impacts of the internet and websites, thorough research was conducted by reviewing academic and gray literature, as well as web sources. While websites have many environmental impacts, the focus of this project was limited to energy-efficiency in relation to GHG production. Descriptive research was also conducted to collect tangible methods and best-practices for sustainable front-end development.

Development:

2 versions of the client site were developed following the timeline displayed in the Gantt chart. Version 1 was the final client site created in collaboration with TNT Retreats, LLC for VCT 4670. This site was developed normally, without regard to sustainable development research or best-practices. After the completion of the first version, Version 2 was then

developed implementing the chosen sustainable best practices. Both sites have identical front-end design. The following sustainable methods were implemented into the development process of version 2:

Version 2 Method	Implementation
Reduce image file size	All site JPEG and PNG images were uploaded into the free Optimizilla online image optimizer tool to reduce the size of the image files while maintaining the existing quality. Images were then replaced in the server images folder and renamed accordingly.
Minify HTML and CSS code	All HTML and CSS text was copied into the free HTML Minifier tool and replaced in the server files.
Reduce attached file size	The downloadable PDF was compressed using the free Adobe Acrobat tool to the smallest file size and lowest quality. The file was then replaced on the server and renamed accordingly.
Local Font Families	The ‘Special Elite’ and ‘Lato’ web font families were downloaded from Google Fonts and a web font kit was created using the free Font Squirrel tool. A fonts folder was added to the hosting server and font kit files were uploaded to the folder. The former external Google Fonts css link was removed in HTML files. Local font-families were created and called using the @font-face selector in CSS.
Enable caching	Caching was enabled to reduce the number of individual HTTP requests by adding the following code to the HTML files <meta Cache-Control: private>.
Site Speed	Site speed was measured and compared from the original site url and the sustainable version url to see which page loaded faster. The Google PageSpeed Insights tool was used.

All mentioned tools are linked in the appendix.

Testing:

To measure the sustainability of both versions, the CO2 emissions were determined using the Beacon Google Chrome Extension. Once installed to Google Chrome, any site's URL can be tested with the tool. The measurement tool estimates CO2 emissions for initial and return visits. The tool also returns a page breakdown of the different visual elements of the site, displaying data on CO2 emissions, file size, HTTP requests, and everyday equivalents. The Beacon website vaguely describes how estimations are calculated, "Beacon calculates the impact based on data transmission which we can accurately measure [using] two numbers that [represent] kWh per GB and CO2 per kWh" (Beacon). Data on GHG emissions and page weight was collected from each site using this tool. To determine if the sustainable development methods were effective in improving site sustainability, the data provided by the Beacon tool from both versions was compared.

Interdisciplinary

This research combines the interactive media - web development and environmental science disciplines. By reviewing current literature on sustainability in the digital world, applying the findings to the development of a client site, and measuring the results, the fields are intertwined to create an interdisciplinary project of original scholarship.

Results & Conclusions

The following sites were developed in collaboration with community partner TNT Retreats, LLC and are currently being hosted on a student hosting site for testing purposes:

Click here to view version 1 (normal development process).

Click here to view version 2 (sustainable development process).

The following data was generated from the Beacon Google Chrome extension and is assumed to be accurate.

	Site Version 1	Site Version 2
CO2 Emissions First Visit	0.759g	0.634g
CO2 Emissions Return Visit	0.703g	0.585g
Page Weight	927.7 KB	775.58 KB
Image CO2 Emissions	0.647g	0.496g
Image File Size	790.79 KB	606.2 KB
Font CO2 Emissions	0.055g	0.083g
Font File Size	67.2 KB	101.19 KB
Stylesheet CO2 Emissions	0.031g	0.030g
Stylesheet File Size	38.43 KB	37.12 KB
Script CO2 Emissions	0.024g	0.024g
Script File Size	29.32 KB	29.33 KB
Document CO2 Emissions	0.002g	0.001g
Document File Size	1.95 KB	1.76 KB

From the data generated, it is revealed that the sustainable development methods were effective in reducing carbon emissions and improving site energy efficiency according to the tool that was used. Version 2 emits 0.125g less of CO2 per initial visit and 0.118g less each following visit. The page weight of version 2 is 152.12 KB less than version one resulting in faster load speeds and an overall better user experience. The site images appear to make up the bulk of the sites' page weights and CO2 emissions. This means that the image optimization method was the most effective and substantial development tool in reducing the environmental impact. Image optimization reduced CO2 emissions by 0.151g in version 2. The images also load much faster with the reduced file size.

Since the 2 versions are visually identical, the development process for version 2 did not add an excessive amount of time. Implementing these sustainable methods would not add an excessive workload for developers if they became industry standard, or common practice. In addition to providing environmental benefits through energy efficiency and reduced GHG emissions, the methods from version 2 have the potential to increase business Return On Investment. By increasing page load speed through the decreased page weight and HTTP requests, site users will likely have a better experience on the website which could lead to return visits and more profit for the business.The benefits from implementing the sustainable methods far outweigh the small costs of a little extra development time. None of the methods that were implemented negatively impacted the front-end design of the website. All of the changes took place within the code and the assets used in the site.

Project Strengths

Due to a lack of awareness about the environmental impact of the internet, research in this area is limited. This research project fills a gap in providing additional evidence in support of sustainable web development. Another strength of this project is the application to a real client project. This project goes beyond making recommendations for sustainable development by putting them to the test in a measurable way to prove effectiveness.

Project Limitations & Assumptions

Measuring the environmental footprint of the digital world is a very complex problem, involving numerous environmental impacts at numerous points throughout the technology life cycle. The internet has many other environmental impacts including physical land, resource use, e-waste, and water consumption. For the sake of this research project, the scope had to be limited to energy efficiency and greenhouse gas (GHG) emissions in relation to websites. These are all areas for potential future research.

Due to the technological and geographic complexity of the internet, tools for measuring CO2 emissions and energy consumption are very limited. As a newer area of research, only 3 potential tools were identified for use in this study. These tools generate data based on calculations that come from estimations. The free Beacon Google Chrome Extension was chosen because of access limitations and the ability for implementation. Due to limited testing tools, it must be assumed that the data generated is as accurate as possible.

Green Hosting may be the most effective way to reduce the environmental impact of the digital world. Due to the budget of this project and the access to hosting servers, this was not an option for this specific site build. The sites are currently being hosted through WH4S (Web

Hosting For Students) which is not a green host. That being said, the recommended sustainable development practices are an effective and efficient way for front-end developers to directly reduce the environmental impact of their work when green hosting is not available.

Future Implications

Web developers and business owners have a moral obligation to consider the environmental impact of their websites and make the choice to develop sustainably. More education is needed to spread awareness about the environmental footprint of the digital world and to bring environmental consciousness to this field. Future research & development is needed in the creation of website environmental impact measurement tools with transparency on calculations and estimations. The environmental impact of web design and development is significant enough that sustainable development should become an industry standard practice.

Considering the review of literature on the internet's environmental impact and the effective sustainable development methods, industry regulation may be needed to make a significant impact. Policy solutions may be an effective option for reducing GHG emissions from the internet or facilitating the shift to renewables in powering data centers. The site that was developed for this project may not see high volumes of traffic or create a huge environmental impact, but if big companies began implementing these sustainable methods into their websites, or if sustainable development became an industry standard, the collective impact could be significant.

Appendix

Tools Used:

Hosting	https://webhostingforstudents.com/
Image Compressor	https://imagecompressor.com/
Minifying Code	https://www.willpeavy.com/tools/minifier/
PDF Compressor	https://www.adobe.com/acrobat/online/compress-pdf.html
Google Fonts	https://fonts.google.com/
Font Kit Generator	https://www.fontsquirrel.com/tools/webfont-generator
Page Speed Analysis	https://pagespeed.web.dev/
Beacon Google Chrome Extension	https://digitalbeacon.co/

Final Websites

Version 1	https://hannahbebinger.webhostingforstudents.com/TNT_Retreats/
Version 2	https://hannahbebinger.webhostingforstudents.com/sustainable-version/

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