Introduction

Infrastructure is and has always been a key component of our civilization and lives, contributing to our adaptation, development, and growth as individuals and as a society. Some forms of infrastructure include the roads traveled, the bridges made to connect various portions of land, the buildings used in our everyday lives, and many more. Due to the assistance of today's infrastructure, we as a society have managed to accomplish plenty of achievements: making groundbreaking discoveries in scientific fields, communicating and sharing information and ideas relatively quickly, establishing and maintaining connections with one another regardless of distance, and more. We have come a long way in our development and growth, and with the help of today's infrastructure, this journey and the achievements that come along with it have become more attainable. However, these infrastructures were not always made the way they are today. Similarly to ourselves and our society, our infrastructures had to undergo many changes and alterations in order to achieve their peak performance. In this article we explore the development of infrastructure, examining the core and foundation of infrastructure dating back to the 20th century, looking at the material used and the reasons for replacing those materials with the ones used in today's infrastructures. From there, we examine the changes leading up to the development of today's infrastructure along with the problems these infrastructures may be facing today. Finally, we examine and explore potential changes today's infrastructures may undergo.

Infrastructure Materials of Early 20th Century

To begin, infrastructures made in the 19th to 20th Centuries were structurally different compared to infrastructures that exist today, primarily constructed with wood. When examining the materials used in these infrastructures, it was seen that wood was a prominent material used in its construction. When looking at the geographics of the United States, at least "one-third of the area of the United States [was] forest land" (Minnesota Department of Transportation, n. d.). With the abundance of wood present at the time, it is not surprising that wood was a primary construction material for infrastructures. Wood could be collected, processed, and used whenever needed, and due to this availability and luxury of wood justifies its prominent existence in the majority of infrastructures in the 20th Century. In addition to its abundance, if modifications were made with wood then it essentially became a very good material for infrastructure construction. In one account, the integration of materials such as synthetic fibers into the wood would result in "greatly [increasing] the bending strength of wood beams and reduce costs of major load carrying members" (Moody, n.d.). Wood by itself is already durable enough to withstand a good range of compressive force and remain intact. With this enhancement of the strength and durability of wood, along with its abundance throughout the United States, wood would be the best choice for infrastructures and its construction in the long run; this further justifies its prominent appearance in infrastructures made back in the 20th century. Although wood had become a good source for infrastructure construction, there arose some issues with using wood which in turn led to a search for potential solutions to address these issues. Certain conditions had to be met when working with wood. As stated, wood was a durable material in itself already, but it was "susceptible to decay or insect attack [and] when protected from moisture" does it become a very durable material (Minnesota Department of Transportation, n. d.). Using wood was a good choice at the time due to the benefits it provided, but it had some vulnerabilities to it as well. Having to meet certain conditions could become problematic both in terms of infrastructure projects and the condition of the infrastructure. If conditions were not met then unexpected outcomes could arise, such as wooden beams breaking from condition or burning down due to fire, and could lead to the destruction of the infrastructure, potentially resulting in costly repairs and reconstruction.

First Steps Towards Modern Infrastructure

With these potential issues in mind, discussions regarding the usage of wood in the long-term and its potential replacements, integration, and usage of other materials in infrastructure construction, and plans regarding infrastructure construction and public work would begin to circulate. In addition to these concerns, events such as the Great Depression that arose in the United States in the early 20th Century contributed to the search for potential solutions and caused subjects such as sustainability to become a more common topic for discussion. Luckily solutions were provided thanks to advancements in technology and the introduction of potential alterations that appeared in the early parts of the 20th century. One solution concerning material replacement comes from the rise of the steel industry and the production of steel. Due to the cost difference between steel and wood, steel replaced wood as a primary construction material for infrastructures such as bridges (Minnesota Department of Transportation, n. d.). Steel was cheaper to use for construction compared to using wood. Compared to the knowledge and experience with wood, and given that it was a new product at the time, the capabilities and value of steel, such as its durability and strength, were unknown, reflecting the fact that steel was less expensive than wood at the time due to its true value being unknown. In addition, with the occurrence of the Great Depression, there was an emerging financial crisis that arose throughout the United States. With the Great Depression occurring simultaneously with the introduction of steel, steel quickly replaced wood due to it being a better financial choice overall. This change in primary construction material usage resolved the concerns of wood replacement and was a very effective change in construction material considering steel is still used and seen in today's infrastructures. In addition to steel, cement soon also became a key material to be used in infrastructure construction, being used in the forms of concrete and reinforced concrete. Concrete, created from a mixture of water, cement, and aggregates, gradually gained acceptance and popularity throughout the 20th Century due to the compressive strength it provides, which is essentially the primary benefit of concrete. From a table containing varying compressive strengths from a conducted experiment, depending on the makeup and ratio of the materials used in the concrete along with the time allowed for the curing period to take place it may provide a range of compressive strengths; ranging from roughly as low as 46 megaPascal (MPa) to as high as 90 MPa (Y B et al., 2021). Perspectively, 1 MPa is roughly equivalent to 145 pound-force per square inch or 9.87 standard atmospheric pressure, which would mean that concrete potentially can withstand compressive forces ranging from roughly 6,671 to 13,053 pound-force per square inch or 454 to 888 standard atmospheric pressure. With material that can withstand this much pressure, buildings would be able to withstand a significant amount of pressure and still remain standing and intact. With the integration of additional materials such as metal bars or steel, otherwise known as reinforced concrete, concrete has the potential to withstand even more pressure and gain more strength, in terms of compressive and tensile strength, and durability. With the combination of steel and concrete, the issues of material replacement for wood and future concerns regarding durability and strength for infrastructures that arose in the early 20th Century would be resolved. In terms of the shift in the methodology of infrastructures in the early 20th Century, as mentioned above due to an emerging financial crisis caused by the Great Depression it sparked discussions and plans to be made regarding the "necessity of long-range planning of public works for stabilizing the economy," (Malekpour et al., 2015). This long-range planning contained the topic of "natural resources development and conservation, to deal with the growing demands of urban populations," (Malekpour et al., 2015). Within the field of public works and infrastructure, acknowledging that the economy was hurt meant that changes needed to be made in order to mitigate the effects of the Great Depression and hopefully restore the conditions of the US economy. Having to use wood would not only be financially difficult and cause more potential harm to the already hurting economy but would also result in draining the wood resources around them in order to meet population needs. The only way possible to make all ends meet was to look for cost-effective replacements for wood usage in construction. This need resulted in the usage of steel in infrastructure to take place. Once again, with steel being new and unknown it was sold and used cheaply compared to wood and by making this change there is hope for change in and stability of the economy.

Conflicts of Modern Infrastructure

Next, the materials used in today's infrastructures may be subject to change due to environmental conflicts and climate-change related problems infrastructures may be causing, one material in particular that is contributing to these problems is concrete. Along with wood, steel, and concrete, today's infrastructure may also be constructed with materials like asphalt, bricks, polymers such as plastic and rubber, and various composite materials. All these materials provide various forms of benefits, such as efficiency, durability, sustainability, and more, but they may also contribute to issues of climate change seen today. When looking at infrastructure and its correlation to environmental challenges it "facilitates a recognition of the ways that the current planetary 'crisis' or 'emergency' is not only a product of the failures of infrastructure, but the logical outcome of its effective functioning," (Macklin, 2022). Through the construction of infrastructure, regardless of its success or failure, its constructive process contributes to the environmental challenges faced and seen today. The method may meet the desired outcome and goal, but the effect it produces may be consequential. Even if the method were the best and most efficient it may not be the safest in terms of environmental preservation and protection. The topic regarding the duality of the effects of infrastructure production, the good and the bad, has begun to arise. Leading to comments circulating around "[infrastructure having] world-ending potential that is becoming even more apparent" (Macklin, 2022) and revision of our concept of infrastructures, thinking about infrastructure "not just in terms of the infrastructure of emergency but also in terms of infrastructure as emergency" (Macklin, 2022). This change in the perspective of infrastructure demonstrates the rising awareness of the entirety of the effects that infrastructures and their production is having on our world; showing acknowledgment of the benefits that infrastructures provide, but also the consequences of their construction and the process leading up to its completion. Infrastructure provides many benefits, such as shelter, human and civilization development, and connectivity, but in itself can be dangerous and cause unintended consequences to arise. One way in which infrastructures have become hazardous is through the materials used for their construction. In particular, the usage of concrete has become a greater concern due to the environmental conflicts it has created and contributed to. The production of concrete requires a significant amount of natural resources. To provide an overview of the number of resources required, it takes "approximately 1.6 tons of raw materials to produce one ton of Portland cement," (Spelman & Lee, 2022). From the United States alone, roughly "[102 million metric tons of Portland cement was consumed in 2020], meaning that roughly 163 tons of raw materials such as limestone and quality clay are needed" (Spelman & Lee, 2022) for the purposes of cement production and usage. From these numbers, it is clear that concrete usage has created great environmental strains. With this much raw material being extracted annually solely for the production of concrete, eventually all the resources of the environment will be completely used up. This will result in many environments having severe depletion of resources and potentially leading to vast destruction throughout environments or destruction in its entirety. Another environmental conflict stems from the disposal and demolition of concrete. In the aspect of infrastructure construction or repair, it is seen that "construction debris contributes a large fraction of solid waste disposal problem, and concrete constitutes the largest single component," (Meyer, n.d.). Solid waste has already been an environmental issue seen in today's time. Seeing that concrete contributes to a significant portion of solid waste existing today demonstrates the role and impact concrete has on today's environmental issues; this being that concrete is a major contributor to environmental burdens caused by unsolved solid waste disposal problems. In addition to environmental conflicts, concrete usage has become a greater concern due to its contribution to climate change and greenhouse gas (GHG) emissions. Looking at concrete production, one byproduct that arises is carbon dioxide (CO2) which is "known to be a greenhouse gas that contributes to global warming, and the cement industry alone generates about 7% of it," (Meyer, n.d.). From a rough estimate, "the production of one ton of Portland cement causes the release of one ton of CO2" (Meyer, n.d.). Nearly a tenth of total GHG emissions produced in the world solely comes from cement production alone. This may not seem like a huge portion, but it is astonishing that nearly ten percent of total emissions are strictly coming from the cement industry and production. In the aspect of how much CO_2 is released, as stated previously, in a year roughly 102 million metric tons of Portland cement is consumed. One metric ton is roughly equivalent to 1.1 US tons, this would mean that roughly 112 million US tons of Portland cement are used a year. This translates to roughly 112 million tons of CO_2 being produced and released into the atmosphere per year. Knowing this amount of CO_2 is potentially released into the atmosphere yearly and that roughly a tenth of total GHG emissions are produced by cement production alone is almost unbelievable to hear about, but clearly shows the extent to which cement and concrete have contributed to the rise and effects of climate change and global warming.

Potential Changes Within the Infrastructure Field Moving Towards the Future

With global warming and climate change becoming more prominent today, questions and concerns arise regarding ways to mitigate GHG emissions within the infrastructure field. In response to this, there has been an emphasis on taking more sustainable approaches in order to combat the issues of climate change and environmental conflicts that infrastructures and their construction process have contributed to. One approach taken into consideration is to rethink and carefully consider the design of infrastructures. Taking the time to think about the design and materials, specifically which will be used and their quantity, may help produce significant impacts that provide the sustainability sought today (Heard et al., 2012). By taking the time to carefully go through the blueprints and designs of a project the overall quantity of raw materials used can be reduced to a point where only a known amount of raw materials are used. With this approach, environments can become more sustainable through the scope that only necessary amounts of raw materials are extracted from the environment for the purposes of infrastructure construction, such as producing cement and concrete. This may also reduce the amount of solid waste that exists in the environment and world since only a necessary amount of materials will be used; with no excess materials present then the amount of solid waste will not increase as a result. Another approach taken into consideration is to use recyclable materials or other cementitious materials, such as fly ash, in concrete mixture to reduce the usage of Portland cement. By taking this approach, it promotes "a move toward circular economy, avoids the cost, space, and potential environmental burden of landfilling discarded byproducts, and can decrease overall emissions of concrete infrastructure," (Spelman & Lee, 2022). Not only will this approach save money, but it will also contribute to mitigating and resolving known environmental concerns and burdens. By using recyclable materials and other byproducts, such as fly ash, the amount of waste added to landfills will be reduced; therefore, showcasing that steps are being taken toward resolving existing environmental concerns. Additionally, this approach would result in a reduction in cement production. By reducing the overall amount of cement produced and used less GHG emissions will be created as a result. The reduction of GHG emissions would potentially contribute to somewhat mitigating the severity of the effects of global warming. Overall, this approach demonstrates that steps are being taken towards sustainability within the infrastructure field today, for the future of infrastructure, and for the future in general. In addition to these steps, an approach toward the creation of environmentally friendly materials is currently in progress within the field of concrete production. This newly developed material is called the biologically-hardened concrete masonry unit (BioCMUs). This material promotes the integration of microorganisms into aggregates to “initiate a setting process similar to how natural stone is created” and “also show promise in enabling ‘self-healing’ concrete,” (Spelman & Lee, 2022). With this new material, potentially the usage of concrete and cement may be reduced, which would also mean that the effects that come with cement production would also be reduced; once again demonstrating that steps are being taken toward sustainability. This new material may potentially save a lot of time and money considering there is a possibility of having self-healing concrete. With self-healing concrete, repairs and reconstruction on damages seen on infrastructures would not be needed given that theoretically this new concrete will be able to fix and repair itself, which would mean that money used towards infrastructure repair would essentially go away. Showing that the creation of this new material may be good financially and once again demonstrates that steps are being taken towards a more sustainable present and future.

Conclusion

In conclusion, in this article we have explored the development of infrastructure throughout time. Firstly, discussing the usage of timber in infrastructure existing in the early 20th Century due to its abundance and durability during that time. However, due to crises that occurred during the 20th Century and with using timber, there was a need to replace it as a primary construction material. Secondly, we explored this process of replacing timber and discovered the introduction of steel and cement, which was swiftly incorporated into infrastructure construction as a primary material and can be seen in many infrastructures built today. Next, we explore the issues that today’s materials used in infrastructure have caused; particularly how cement has contributed to prominent issues, such as environmental concerns and climate change, occurring in today’s time. Finally, we explore various approaches and changes toward sustainability to be made in the infrastructure field as we deal with the issues existing in the present and moving onward toward the future.

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