Extending the life: Deep energy retrofit analysis for classroom blocks in New Zealand

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Abstract: The New Zealand Ministry of Education owns 33,000 classrooms, many of which possess low levels of insulation and depend on openable windows for ventilation. Extending the life of existing buildings reduces the number of buildings that end up in landfills and the embodied carbon embodied in the construction of a replacement classroom. The aim of this review is to explore potential retrofit measures towards improving sustainable practices in external classroom block façade and invariably improve indoor quality for children occupying the classroom block. This study adopts a comprehensive literature review of deep energy retrofits of classrooms. The exclusion and inclusion criteria involved the use of keywords such as retrofit, energy savings, education, and lifecycle analysis. A total of 50 articles were reviewed which had a direct impact on extending the life of classroom blocks. The analysis revealed that the current pressure to plan for New Zealand's carbon targets requires a change in design thinking. This change can be provided through the retrofit of existing buildings to extend the life cycle. This will enable buildings that are present to reduce the adverse environmental impacts that they are presenting and will concurrently improve the functional ability of our domestic environment. This simultaneously provides a resource that nurtures the child whilst creating a design that will aid in meeting UN Sustainable Development Goals and will benefit future generations of children. Future research would investigate standardisation of retrofit guidelines for New Zealand classroom blocks.

Keywords: Retrofit; Education; Sustainability; Carbon Impact.

1. Introduction

There is a need to restore and utilise the architecture that is already present within our environments. Where possible extending the life of a structure whilst saving the embodied carbon required of a new build, and the incurring waste of demolition can be offered. Of the 2,100 School blocks across the Ministry of Education's portfolio, over 30 of those are existing Nelson Blocks (Ministry of Education, 2022). During the 1960s the Ministry of Education constructed a lot of schools using a limited number of standardised plans. One design that has been reproduced in all areas of NZ is called the Nelson Block (Ministry of Education, 2013). The form of the Nelson Block is an H shape plan layout with variations of the form.
These blocks were built across the country with little variation despite changes in climatic region. The Nelson block is constructed with raised timber piles, timber framed walls and roof structure, single glazed joinery, and timber weatherboards. The superstructure is usually very solid but lacks any wall insulation. Roof insulation has often been added but to a low R value. The structure leaves a large area for improvement and within this review, insight can be made into what systems and alterations can be made as a solution.

As we live in an environment where the architecture and construction sector define the prospect and future for a city, it is imperative that make the shift towards sustainable practices to provide for future generations. Deep energy retrofits offer an opportunity to utilise existing resources within our educational facilities and government portfolios to integrate this architecture. A deep energy retrofit enables a structure previously in disrepair or tired an opportunity to utilise innovative technologies for vast energy savings of the architecture. Deep energy retrofits not only provide substantial energy savings but allow an opportunity to forming suitable comfort conditions for the benefit of students and teachers within educational sectors (Reiss, 2014).

Educational facilities are often sites in need of refurbishment due to their large footprint, heavy usage, and evolving requirements towards their facility (Park et al., 2021). The modernisation and repair of these buildings allows an opportunity to restore heritage to a site while providing a carbon focus for the benefit of the environment. The prospect of altering and upgrading these common type schools allows for a life cycle improvement and ensures the stylised architecture has an opportunity to be valued beyond its anticipated lifetime. In identifying the boundaries and opportunities of standardised forms of educational architecture, a solution can be formed in addressing the sustainability and carbon impact of these spaces. Currently, poor classroom design and ventilation can lead to mental health effects, illnesses, asthma-related health outcomes, fatigue and lack of productive learning due to these environments (Bluyssen, 2013).

Hence, the aim of this review is to explore potential retrofit measures towards improving sustainable practices in external classroom block façade and invariably improve indoor quality for children occupying the classroom block. The North and South perspective of the Nelson School Block is shown in Figure 1(a) and (b). To achieve this study aim, a case study analysis with a simultaneous literature review of recent studies on retrofit and extension of life of classroom blocks was adopted. Subsequently, a design solution of proposed retrofit system was simulated with key environmental criteria.
2. Literature Review

2.1. Existing Literature

Literature on energy efficiency is vast and broad. The discourse spans a large network of ideas and themes that relate directly to the sustainability of architecture and of how buildings can prosper to be more efficient. This topic can be associated towards a variety of aspects, however the topic of deep energy retrofit narrows the scope and literature into a genre which can be determined through specific internal and external qualities. The idea of a deep energy retrofit reflects the theme of flexibility and the opportunity to provide and transform a space to the character that the site itself presents. This research aims to provide a base that can be utilised towards the broader field of Nelson Block Designs spanning across New Zealand. Existing literature that reflects the integrity of this research can be seen through key authors such as Bob Lloyd (2006), Yu Wang (2020) and Alexander Zhivov (2017). Their work highlights a previous integration for process and innovation into design for achievable and sustainable energy standards. Their research identified the potential for refurbishing and retaining older buildings with an efficient longer life. The central question is how can older low-rise buildings be made viable for the future through being retrofitted with a low energy design system.

The previous study provides a body of work that identifies the positive role of investigating ventilation in schools and the capacity that retrofitting systems in schools provides to the CO2 levels for the wellbeing of students (Wang, 2020). It is worth noting that CO2 is a crude proxy for the occupancy and ventilation rate and sufficient air changes per hour is the ideal measure. This directly highlights the importance of a healthy internal environment and in result correlates to the opportunity of reinvigorating these existing forms of architecture to provide better facilities to the user. Lloyd (2006) presents key precedents in identifying the gaps in current architecture throughout New Zealand and how a variety of systems impact the energy standards of the buildings. His work looks closely at New Zealand case studies and how these effects are felt across New Zealand’s contrasting climate conditions. Discourse highlights how important it is to utilise productive systems within a retrofit and of how the quality of the product results in a direct impact to the energy saving potential.

Zhivov et al’s (2017) range of work looks specifically at the success and results of retrofitted case studies around the world and identifies key technologies that when applied together will reduce a buildings energy by 50%. He provides a guide to achieving large energy reductions and indicates the best achieved strategies to attaining a lower energy space. His broad range of work identifies successful bundle systems for how to retrofit major building renovation and of how to achieve a significant energy improvement. These previous studies all examined case studies where alternating systems can be implemented and allow insight to be made to the success and or failures of how high-performing systems can be applied to architecture within a variety of climates.

2.2. Standardised Blocks

The standardisation of educational facilities is a component to consider within the research of this paper. Designing quality learning spaces is a reference guideline from the Ministry of Education for how their portfolio of buildings can be enhanced to bring the learning spaces closer to the ministry’s recommendations. The assumption within this is that the existing natural ventilation and lighting of these spaces is to an adequate level, however this will be a factor that is reconsidered within this research in order to bring the standard of thermal comfort and ventilation to an improved standard—especially in a post-pandemic learning environment (Ministry of Education, 2016).
The Nelson Two Storey Block is the standardised structure from the Ministry of Education that will be investigated within this paper as shown in Figure 2. This style of architecture was designed within the 1960’s before the introduction of seismic requirements and is based on an H shaped plan layout. The design of each school varies in structure and form, however they all retain similar properties with lightweight timber framing and roofs. The blocks often consist of high windows roughly of a 1m x 3m stretching along the extended bays and contain the equivalent of six classrooms to each floor as seen in the figure below (Ministry of Education, 2022).

Figure 2: Nelson Block North Elevation

The Nelson block is a standardised form spanning across the country in various school portfolios. The design of the standard block provides an opportunity for a retrofit to best utilise the historic properties and style of the original site to be regenerated for use into the future. In consideration of the current design options available through the Nelson Design Features report there is a large scope in improving the thermal and energy performance that are not addressed (Ministry of Education & Aurecon New Zealand Limited, 2016). This therefore presents opportunity towards retrofitting the external structure. The lightweight structure provides a base for a successful deep energy retrofit and offers vast possibilities to not only the layout for internal spaces but the potential for an energy efficient and sustainable space to be created.

2.3. Energy in a retrofit

Energy and the improvement of sustainable practices within this paper will be a change that will happen out of necessity rather than opportunity. The foundation for this research is to aid in providing a regeneration towards the architecture of the educational sector and cited within that is the need to respond to the significant impact that results from past building stock (Zhivov & Lohse, 2017). Architecture and construction contribute towards the largest energy sector in the world. In the case where one-third of total building energy use is imputable to existing buildings it proves the necessity to provide action with the combination of existing buildings and energy use (Rabani et al., 2017).
The concept of retrofitting within this research will aid in reducing the environmental impact of these existing buildings. This will be achieved through optimising the constraints of least cost investments, greatest energy savings and the reduction of carbon emissions (Başarır et al., 2012, Rabani et al., 2017). Retrofitting a school environment is a critical aspect to recognise not only due to the large energy consumption caused by the high-performance builds but also due to the fast evolution and need for alteration to teaching and learning environments (Thi Hoai Le et al., 2021). Retrofitting provides a means to preserving the superstructure which avoids the increase of embodied carbon of a new build. It provides the ability to retain established architecture for the next generation and ensures an efficient design can take precedent towards new and developing school programs (Moazzen et al., 2020).

When considering the implications and advantages between choosing to retrofit an existing building compared to demolishing and rebuilding the structure, the potential to provide an 80% energy saving using passive systems must be considered (Moazzen et al., 2020). This increase in potential energy savings results in the architecture being advantageous and invaluable to salvage and allows the structure to be modified to achieve an ideal thermal comfort. The approach to managing the energy efficiency of an existing architecture can provide a logical approach to a passive and renewable integration towards architecture and ensures the potential to have net zero emissions by 2050 as required by the New Zealand Climate Change Response Act (2019).

Heating and cooling were the focus of this research as they make the most effective shift towards a deep energy retrofit. By improving the envelope of the building and the heating and cooling practices, an incremental change will occur within the space to the benefit of its thermal performance. Schools in New Zealand are an obvious type of building for optimising solar energy as they are typically operated between the hours of 9:00 AM to 3:00 PM which coincides with the hours of highest solar radiation levels. Retrofitted solar systems can include photovoltaic panels for converting solar energy to electricity, which in turn can be used for operation of a heat pump, or solar thermal systems for the conversion of solar radiation to heated air. Solar Air Heaters (SAH) are a relatively easy system to retrofit on low rise buildings and effective for heating an internal environment. Their system is employed to gain useful heat energy from solar radiation in order to heat a space. Their benefits range from the natural resource that is utilised to retain the heat (Preda, 2017; Wang 2020).

![Solar Ventilations in Schools](SolarVenti Australia, 2022)
In the previously mentioned study by Wang (2020), it was found that classrooms fitted with a solar air heater had better indoor air quality, warmer and drier air than matched adjacent classrooms and used their existing heat pumps 2½ times less. The integration of alternative forms of space heating and cooling within the building sector is of high importance especially when considering the vast effects of global warming. The ability to utilise systems that are reliant on natural resources is an opportunity that needs to be utilised. Solar energy provides the potential to fulfil the energy requirements of a space and when considering the efficiency of the system it offers the solution to be carried out across these standardised blocks (Audu et al., 2021).

2.4. Influence of Daylighting

Daylighting is a key concept to identify when considering the retrofit of a New Zealand school. The importance and influence that daylighting can make to an educational environment is critical towards the performance of a student. When looking at the energy savings that can be utilised by advocating for proper daylighting tools within architecture, a significant impact can be made through the reduced need for not only electric light, but cooling needs too (Heschong et al., 2002).

Daylighting is an important criterion to acknowledge as the sunlight determines and further influences comfort levels of the internal environment and therefore the energy consumption of the architecture (Li et al., 2021). Utilising the daylighting principles will allow the majority of building stock to be upgraded to satisfy present day green building standards. They present an opportunity to contribute to the building sector for years to come and when effectively retrofitted, the design measures taken to achieve the quality standard will positively impact the chosen architecture (Li et al., 2021).

Prevalent to the influence of increased daylighting, the opposition to window size and artificial lighting is also a pertinent topic. The period of the chosen Nelson Blocks as described within this review identifies the late 1960’s and 70’s as being the key time of construction. As transcribed within a review of the development of daylighting in schools, during this period, large windows and daylighting influence were negated in exchange for fluorescent lighting and small windows to mitigate screen glare and reflectivity (Barch et al., 2003). This change in schooling design resulted in the preference for air-conditioning units due to the lack of daylighting and sunlight which directly impacted on the performance and focus of the student’s health (Barch et al., 2003).

Daylighting is a critical factor to consider when informing the retrofit of an educational space. Not only for the positive impact it can make towards the student’s performance but also for the benefits that incur from a renewable and efficient source of heating and cooling. Daylighting is an imperative tool to utilise within a deep energy retrofit. Within the building sector electric lighting design can contribute towards 40% of annual building energy consumption, especially in a commercial build such as a school (Wong, 2017). The replacement, where possible, of artificial light is the most direct and efficient way of approaching daylighting in terms of passive solar energy design. Successful treatment of this system and strategy can heavily supplement the building energy consumption and can allow an improvement in the buildings performance standard.

Although daylighting systems provides a vast number of advantages towards a site, there is the necessity for balance in ensuring glare, overheating and thermal discomfort to occupants is avoided. This can be achieved through a variety of daylighting systems such as overhangs, light shelves, louvres, sun tunnels, blinds, screens, and light filters (Littlefair, 1990). Strategies that will be identified as potential
proposals towards this retrofit are influenced through innovative systems that will aid in conserving energy and enhancing the building user’s environment.

In retrofitting the Nelson Block design, the key focus within identifying the daylighting system will be in how the selected system can significantly reduce lighting and cooling loads for the performance of the space. Without the opportunity of a new build to alter the orientation of the site, it is imperative that the strategy will provide optimal natural daylighting into the given space and will ensure applicability of the system for the entire site (Kim & Kim, 2010, p. 256). The potential that daylighting provides towards any environment in reducing the energy consumption by artificial light is considerable (Onubogu et al., 2021). In a space that does not require evening illuminance, like the Nelson Blocks, an opportunity is provided to utilise natural systems in an attempt to aid in the United Nations sustainable development goals.

2.5. Façade Treatment and Glazing

The implementation for systems towards this retrofit span a large network of tools and considerations. For this purpose, it is necessary to limit the scope towards which systems will be addressed within the research. Windows are a wound on the thermal envelope of a building allowing up to 50% of a buildings heat to escape under single glazed environments (BRANZ & Burgess, 2008). Given the low thermal performance that single glazed windows offer, they are an obvious building element to upgrade to increase the thermal performance. Glazing and façade replacement is an initial system within the scope that will be addressed.

Façade treatment and the replacement of their design provides a key influence towards architecture. The façade acts as a barrier and system that is the initial treatment before mechanical air and ventilation come into play. Façade design within the 1960’s was inefficient and acted as a major source of energy and heat loss within the architecture. The ability for this system to be replaced in order to maximise and control internal comfort is an opportunity to be utilised (Martinez & Carlson, 2014).

The importance of identifying and replacing the façade within this deep energy retrofit is due to the opportunity to utilise higher performing products and materials that will ensure an improvement in energy performance and future needs of the site. Within the changing environmental conditions and strategies for building development, façade technology can aid in providing the performance goals that existing and future buildings will be required to meet (Martinez et al., 2015).

Façade treatments are an integral factor to consider due to the ability to reduce energy consumption of a building that was designed when energy considerations were not of a high importance. The building envelope holds potential for innovation and refurbishment through the ability to utilise the system of the façade, and the sub-structure of the framing and panels (Brown & de Wilde, 2012). This replacement can accommodate for a savings of over 50% in energy reduction compared to a pre-retrofit condition when addressed within the deep energy retrofit system (Martinez & Choi, 2018).

2.6. Impacts of Ventilation on a Retrofit Space

New Zealand schools have a large opportunity to provide a comfortable and enjoyable environment for the wellbeing of students while gaining the potential to create a sustainable and regenerative retrofit prospect. The ventilation and indoor air quality of these spaces is an area that can be of great use towards altering the energy efficiency of the architecture. New Zealand classrooms often have low ventilation rates, and high carbon dioxide levels particularly within the winter months (Wang, 2020). This is especially important to acknowledge in light of COVID and the influence of air concentrations for student health.
The importance of acknowledging the ventilation and air quality within an educational environment is also of particular interest where the energy required to heat and cool a space will be impacted with the fluctuation of higher ventilation rates (Fisk, 2017).

Ventilation in classrooms is an everchanging practice where adjustments in efficiency and airtightness are constantly changing. Forming a response to a retrofit concept that allows for alteration and or change to the practice will be necessary. Providing the space with a system that delivers an increase in ventilation and decrease of indoor pollutants (Allen et al., 2016). Recent Studies done by the Ministry of Education investigated experiments for how new systems can be effective on poorly ventilated indoor environments. The study identified CO2 levels within control rooms across a variety of test scenarios which looked at the differing systems of solar air heaters, natural ventilation versus augmented ventilation fans, air cleaners and temperature differential of window openings (Ackley & Phipps, 2022a; Phipps, 2017).

As the study was conducted within a light timber framed classroom with both high and low windows, it is viable to form a close comparison to that of the Nelson Block design. The systems utilised within one of these studies resulted in the findings that natural ventilation can provide the required Air Changes per Hour (ACH) for good ventilation assuming the openings are maintained at 2 m2. Using Augmented systems such as HEPA filter air cleaners can be supplemented when the 2m2 of openings becomes impractical due to weather conditions or thermal discomfort (Ackley & Phipps, 2022b).

A study towards this paper was completed on the Nelson Block design where a simulation model was developed using EnergyPlus, Radiance, and Insul software. This research was completed as an investigation towards how the existing Nelson Block performs in its current state and how implementing new systems can form a positive response towards the results of internal comfort and efficiency.

The design changes carried out for thermal performance included increasing the insulation and shading. For ventilation, an HVAC system was incorporated alongside increased window openings. In terms of daylighting, shading, changes to wall to window ratio (WWR), light shelves, and different glazing properties have been included. For acoustics, acoustic insulation and materials have been added, as well as removing building leakages. From this, results are gained for the performance of design recommendations for the Nelson Block. In order to work towards the goals of a zero-carbon operational building and optimum performance and wellbeing of school building occupants, the priorities for design changes are increasing WWR for passive heating and greater levels of daylighting, adding insulation (plus double glazing) for thermal performance and acoustic performance, and increasing the window openings for appropriate ACH and passive cooling. These design changes are the priorities because they address multiple design parameters in one, whilst fitting within the scope of works proposed by the Ministry of Education.

2.7. User Comfort

The fundamental part of this research will be influenced using energy modelling and simulation of an internal space. As the results that will occur from this modelling will inform the majority of work that is resolved, it is essential to consider the implications of user experience on a space outside of a simulated environment.

The considerations to a student’s environment are critical when identifying how a deep energy retrofit can benefit a child’s experience in a school. As students spend the majority of their educational time indoors it is crucial to ensure the classroom is ventilated and sitting at a comfortable level, which is where the modelling can be utilised as a tool (Domínguez-Amarillo et al., 2020).
With the steady increase in temperatures and the impact of climate change, it is essential to consider the internal comfort of the students in order to ensure their performance, health, cognitive processing, and engagement are a priority (Domínguez-Amarillo et al., 2020).

When positioned in a space that does not suit the comfort parameters that allow a student to perform, a loss of control and management are at the forefront (Majd et al., 2019). Indoor performance plays a crucial role in the experience of a child’s education, therefore through utilising the tools available with simulation-based results, a result that ensures the highest internal comfort level can be reached.

2.8. Sustainable Implications

Benefits towards utilising this idea of a deep energy retrofit instead of a rebuild is dependent on the potential of retaining the sub-structure of a build. Within the process of demolishing a build, the waste accrued increases the embodied carbon emissions of the site through the process of deconstruction, removal, and disposal means of the materials. The carbon footprint of the building is increased and the potential for the building to be of a circular approach is diminished. This is where the deep energy retrofit comes most into play. When retrofitting a build, the substructure and therefore the highest carbon producers of the build remain intact; therefore, retaining and reducing the carbon footprint of the building when compared to a site which is demolished and replaced.

The highest embodied carbon is produced through the demolition of substructures of beams, columns and slabs at a rate of 46%, and the greatest embodied energy comes through the mechanical, electrical and plumbing services at 58% (Gonzalez et al., 2021). When architecture presents itself with the opportunity to retain these key contributors, it has to be undertaken in order to aid the efforts towards a zero-carbon future.

Waste is a factor often overlooked in its implication to the environment. The vast number of metals, oils, scraps, and plastic that are in our environment once their product life is classified as over is immense. The opportunity to recycle and avoid the environmental hazard that comes with this end of life is prominent – especially within the building and construction industry. Within this project comes to opportunity to recognise the waste accumulated by this industry and to provide an opportunity to recycle and reuse. Product life cycle assessment will aid in forecasting the impact of the selected materials and will ensure the potential to design for disassembly (DFD) in order to aid and facilitate further recycling at the end of the building’s life cycle (Gonzalez et al., 2021).

3. Research Design and Methodology

The Methodology behind this project begins with research about design to inform current practices with the New Zealand context of education and the limitations that a retrofitted form will produce. It will prospect into case study analysis with a simultaneous literature review to examine the dimensions extended by this study (Ackley & Phipps, 2022a; Phipps, 2017).

Research led design will lead the secondary part of the research where the design of the retrofit system through simulation of key environments and a series of phases in connection with this research will ensue. Researching through design will form the foundation for this research where in concluding on the specified systems, a design will be ascertained (Groat & Wang, 2013).

A key focus on the improvement of current practices regarding re-design within the educational sector should aid in providing a resolution to the state of existing dilapidated schools with considerable room for
improvement. Through creating boundaries for application of the research and through methodical analysis of each of the systems, a proposal can be structured as a response to the retrofit of the Nelson Blocks.

Through the analysis that was performed on a Nelson Block example; of Nayland College in Nelson, New Zealand, a summary could be concluded in consideration to design proposals, literature reviews, and environmental building simulations. With particular regard to the thermal performance, ventilation, lighting, and acoustics - EnergyPlus, Radiance and Insul were used to develop a model which tested a range of design alternatives. In order to work towards the goals of a zero-carbon operational building, optimum performance and wellbeing of school building occupants, the design changes that were summarised and in conclusion should be a focus within future research include increasing WWR for passive heating and increasing levels of daylighting, adding insulation into the walls and floor (plus double glazing) for thermal performance and acoustic performance, and increasing the window openings for appropriate ACH and passive cooling. These design changes are the priorities because they address multiple design parameters in one, whilst fitting within the scope of works proposed by MOE. Overall, the occupant comfort and performance levels will increase as a result of all of the design interventions stated, working towards a zero operational energy goal indicated through the energy balance.

4. Discussion

There are many tools and resources that can be identified when considering a deep energy retrofit, however a school presents new opportunities and considerations. In taking into account the implications for how these systems influence the performance of the standardised block, an effective resolution can be formed towards the future of New Zealand school design.

The results from the anticipated system design will implicate the performance of the build in a variety of ways. Through altering the glazing and façade solutions by selecting systems such as light shelves, translucent louvres, overhangs or low e glazing replacements, a result can be formed in terms of adjusting the daylighting and overall performance of the solar and thermal intensities as present during the course of the school year.

Going forward, each of the aspects of the walls, roof, glazing, façade and floor of the original structure will be analysed further than the initial study in order to form a comprehensive understanding of the implications towards altering each component.

The need for a deep energy retrofit will allow for any of the Nelson Blocks across the six climate zones in New Zealand to be responsive towards the changing conditions that are required for the performance of schools in the current environment. This research is necessary in order to provide an example to how you can build for existing architecture and for how architecture can be resilient for the future. In providing the opportunity to bring new life into existing buildings a strategy needs to be made in how we can best utilise the form that is existing and make it suitable for future use.

This research also provides insight into not only the retrofit of educational spaces but also provides an opportunity to utilise this knowledge and methodology towards other types of building stock. Through utilising the same strategy and technique, a system could be implemented into informing the performance of other facilities that are underperforming. The retrofit allows possibility into what design can offer for the lifecycle of existing buildings and to how they can be redefined for use well into the future.
By considering the technological advancements and renewable sustainable systems that can be implemented into a retrofit design, a proposal can be made into altering existing property portfolios. In our preliminary results shown in Figure 4 (a) as the base model and (b) as the model with alteration, there is significant growth in energy performance to achieve a higher internal comfort rate from 10% to 77% with basic changes to the whole building envelope. The research into further analysis is currently ongoing and the final results will be presented in subsequent articles.

5. Conclusion

Deep energy retrofits offer the opportunity for existing building stock to be reinvented and to restore its life towards the use for future generations. It allows architecture to reinstate not only the embodied energy of the original building but also the impact of the structure on carbon emissions. In an environment where every architectural move and decision causes a permanent response, utilising the resources that are already present is essential.

The standardised Nelson Block by the Ministry of Education not only provides this opportunity to reinvigorate existing buildings, but to improve the quality of comfort and learning within schools that the
future generations are accustomed to. In upgrading schools and educational spaces, a tool is produced through the enhancement and increased performance of these spaces. One that provides opportunity towards the future of old building stock, and one that allows existing architecture a means to augment their estimated lifecycle.

References


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