The Innovation Hub

for Affordable Heating and Cooling

Design Studio Outcomes Report (100% Milestone)

IDS-06 LXRP Transport Buildings

Project IDS06

27 May 2022

The University of Melbourne

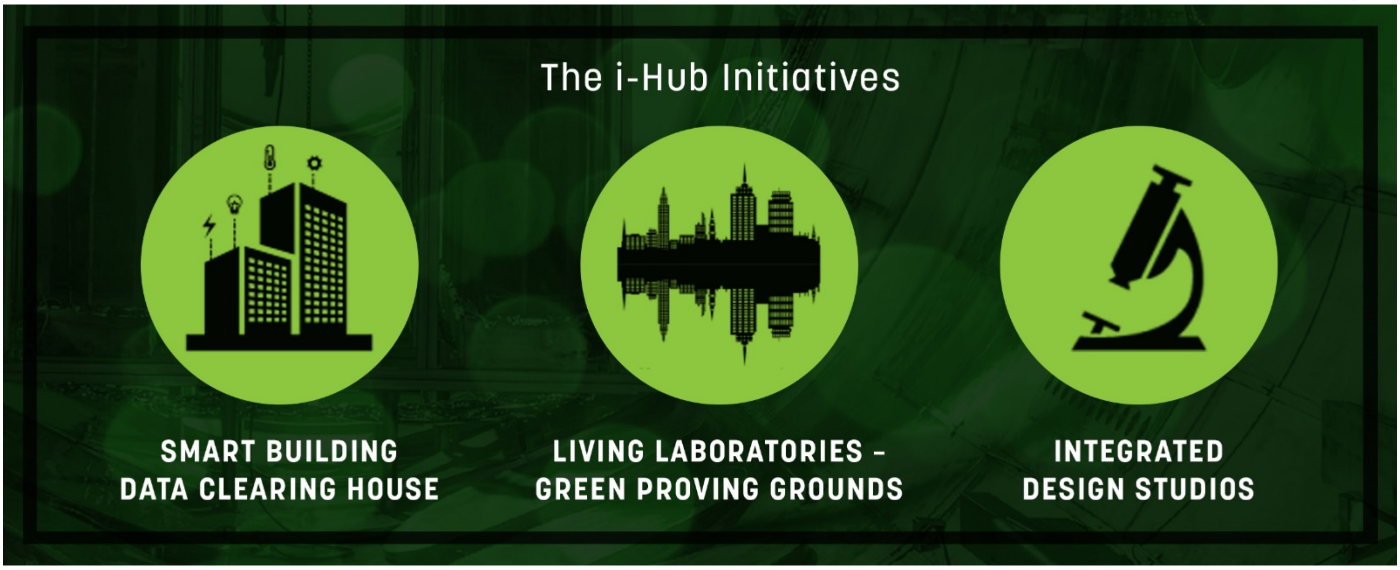
About i-Hub

The Innovation Hub for Affordable Heating and Cooling (i-Hub) is an initiative led by the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) in conjunction with CSIRO, Queensland University of Technology (QUT), the University of Melbourne and the University of Wollongong and supported by Australian Renewable Energy Agency (ARENA) to facilitate the heating, ventilation, air conditioning and refrigeration (HVAC&R) industry's transition to a low emissions future, stimulate jobs growth, and showcase HVAC&R innovation in buildings.

The objective of i-Hub is to support the broader HVAC&R industry with knowledge dissemination, skills-development and capacity-building. By facilitating a collaborative approach to innovation, i-Hub brings together leading universities, researchers, consultants, building owners and equipment manufacturers to create a connected research and development community in Australia.

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.
The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Primary Project Partner



i-Hub Design Studio Outcomes Report (50% Milestone)

The IDS-06 LXRP Transport Buildings Integrated Design Studio, investigates design innovation to reduce net energy consumption using renewables and other energy technologies. Over a 14-week period, a group of architecture and engineering students work jointly with Engineering experts to develop linear infrastructure facilities. These types of facilities are known to have high operational energy requirements.

Based on a project brief presented by the client, students explore novel approaches to develop a LXRP Transport Buildings within the wider Melbourne area. Particular focus is given to the intrinsic nature of the layout of such centres and their environmental affordances, by integrating novel technologies that provide synergies with various programmatic requirements, functional considerations, and overall aesthetics, thereby significantly reducing its carbon footprint.

Lead organisation	The University of Melbourne		
Sub-Project number	IDS-06		
Sub-Project commencement date	21st July 2021	Completion date	27th May 2022
Report date	27th May 2022		
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1. SUMMARY

1.1 Purpose

This report summarises all findings taken from IDS-06 and marks the 100% completion milestone at the end of the project. Information inherent to this report will flow directly into the 'Lessons Learned' from IDS-06 and they will be further disseminated under the IDS Knowledge Sharing Strategy associated with the program.

1.2 Executive summary

The IDS-06 LXRP (Level Crossing Removal Project) 'Transport Buildings' was initiated late July 2021, after substantial stakeholder engagement with their client representatives back in Q1 of 2021. In line with the approach taken for the IDS run the semester before, it was intended for this IDS to be run entirely as a face-to-race class at the Melbourne University campus. The IDS steering committee therefore searched to secure participation of architecture and engineering students, who could interact in person with each other and the industry advisors throughout the duration of the semester (experience on prior IDS showed that this setup is the best option for collaboration). The focus on face-to-face teaching led to difficulties in securing the participation of the desired number of Engineering students, as many are currently offshore due to the pandemic. In addition, changes to access to the university campus due to continued lockdown restrictions from week 2 of semester, have affected the plan to teach face-to-face. Apart from the site visit, teaching had to resume entirely online for the remainder of the semester (yet too late to still enable the IDS steering committee to introduce more Engineering students to the IDS cohort).

Each of the 13 students (comprising 12 architecture students and 1 engineering student) advanced their ideas in groups. Group-work included research and design exploration exercises, and the development of design proposals. The architecture and engineering students interacted with the studio leader twice a week, and on a weekly basis with the industry advisors. A dedicated 'Catalyst for Integrated Design' guideline underpins the collaborative effort and helps in the joint development of common goals toward 'Net Zero' design. The two weekly studio sessions are being held online this semester, allowing the team of UoM academics to diligently observe and analyse the integrated design process as it unfolds. High-level observations of the integrated design effort point towards lessons learned, which include:

- Visual communication can be understood universally across disciplines, through specialised visual conventions and holistic shared language.
- Documentation can be used as an analysis exercise, providing new perspectives on structures and systems.
- Sustainability outcomes are client outcomes and are most convincing when intrinsic to a holistic narrative
- The intentional introduction of interdisciplinary themes has a significant impact in facilitating an interdisciplinary dialogue and cohesive narrative for a design team.
- A shared collection of holistic goals, self-assigned early in the project, help to guide design responses within a strong and adaptive narrative framework.
- An informed process of interrogation and iteration help to develop and optimize a scheme informed by valuable engineering insight.
- The contrast of 'inserting' design features and 'integrating' design responses demonstrates the strength of a strategy and level of engagement in integrated design. Sustainability is best achieved when it is integrated at all scales of the design.
- The final documentation phase of design projects is challenging, freezing integrated innovation as the pressure of time, and pending assessment, increases.
- Materiality is a nexus of integration, drawing together architecture, structure/ construction, and sustainability.
- An integrated design team is most effective when the social environment is a comfortable space, encouraging innovation and experimentation, built on strong social connections.
- An appreciation of other disciplines' knowledge helps designers make connections and integrate effectively.
- Empathy and respect in a team opens discussions up, allowing contributions from all team members to be engaged with, not just that of one discipline or those which are positive or aligned with the existing scheme.

2. PROJECT CONTEXT AND INCEPTION

2.1 Context to the LXRP Transport Buildings - Integrated Design Studio

In the lead-up to University of Melbourne's start of semester, Prof Brendon McNiven from the Faculty of Architecture, Building and Planning, and Prof Lu Aye from the Melbourne School of Engineering had engaged in intensive industry consultation in order to search for compelling case-studies to investigate new technologies under the Integrated Design Studio banner. This IDS ran during Semester 2 2021, which spanned over 13-15 weeks from late July until early-mid November.

The LXRP Transport Buildings project embodies a programmatic and functional specificity that promises a fertile testing ground for design exploration, particularly when considering Zero Carbon constraints. A detailed technical brief and program for the linear infrastructure and station have been provided early in the semester to ensure rigorous conformance with the constraints of rail typology. However, the conceptual brief for the project remains open, directing participant focus to the exploration and development of schemes that connect with the community context through iterative environmental and engineering responses.

In the weeks leading up to the start of semester, the Melbourne University team went on to gain University of Melbourne internal *Ethics Approval*, select the Design Studio tutor, establish the context for the IDS to integrate seamlessly with the existing curriculum, and chose the industry advisors to join in on the project.

2.2 Studio Inception

Several kick-up workshops took place at the start of Semester 2, to introduce all studio participants to the IDS principles, as well as providing a platform for stakeholders to get to know each other. Due to the COVID-19 context, these workshops occurred online. It was decided to split the initial workshops over several classes in early August (during the first two weeks of semester). The workshop sessions included presentations from the IDS research team, University of Melbourne academics and the participating advisors.

Next to the benefits for information exchange, the initial kick-off workshops also fulfilled the essential task to introduce all key IDS participants to each other and facilitate social bonding, particularly between architecture and engineering students.

2.3 Client Engagement

This IDS is working without formal client representation; however, the client is the Victorian State Government, and their priorities are well understood by participants, particularly the target of Net-Zero Carbon 2050. An experienced independent architect takes the role of client representative at milestone reviews to provide appropriate feedback on the proposed designs. The IDS-06 LXRP Transport Buildings project is joined by industry advisors, specific to the Victorian State Government LXRP venture with experience in architecture, structural engineering, construction and sustainability. The combination of the advisors' expertise and the client representative's willingness to experiment provide ample space for participant designs that are both ambitious and respond to the real-world considerations.

2.4 Site Visit

The site of the transport buildings is the Frankston rail line through the Melbourne suburbs of Edithvale, Chelsea and Bonbeach. Each team had the opportunity to select one of the three stations to be the focus of their project. The ease of access to the site, using public transport, in the first two weeks of semester, provided the participants the opportunity to visit the project context and nearby recent infrastructure upgrades. A site visit occurred in the second week of the studio (figure 1(a)), which COVID-19 restrictions allowed, providing the participants with a nuanced understanding of the different demographic, civic and environmental considerations relevant to this project. The site visit appears to have impacted participants greatly, all teams frequently return to the station function for the range of demographics specific to their suburb as well as the commercial and civil context of their station proposals.

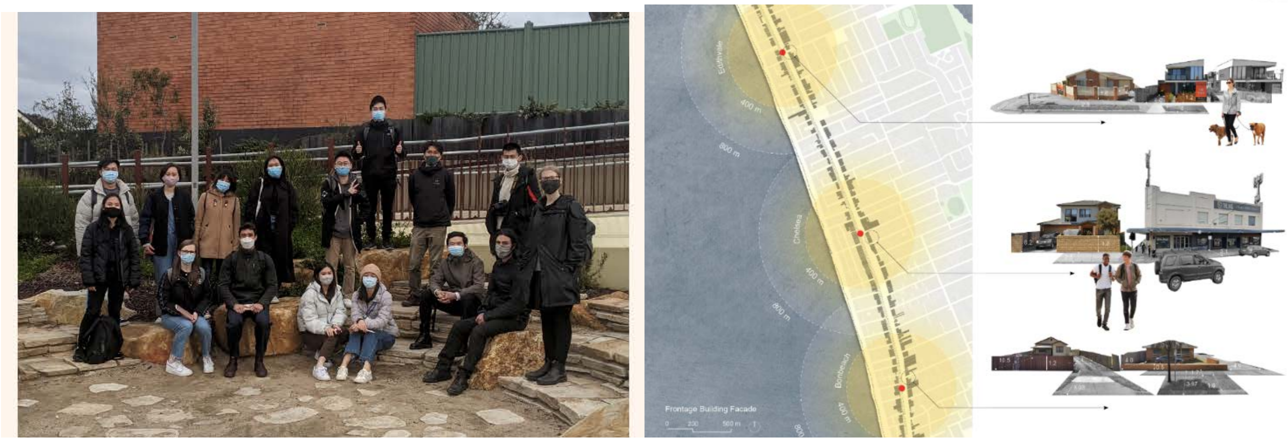


Figure 1: Site analysis consisting of both (a) in-person site visit, (b) supplementary desktop demographic research.

3. DESIGN STUDIO PROGRESSION

3.1 Setup for Collaborative Design Integration

In order to provide guidance for the programming of Design Studio activities, and in particular their interface with the investigation on integrated design, the IDS management updated their detailed manual titled: *'Catalyst for Integrated Design'.* Released approximately 2 weeks before the studio's commencement, it combines aspects of design collaboration that cut across architecture and engineering disciplines, and it ties directly into the studio-teaching process. The manual first addresses overarching aspects of design integration to then delve into the specifics of environmental building performance, human comfort, and mechanical design systems. The manual ultimately assisted the studio tutor to coincide their activities for advancing design concepts with key milestones for addressing and integrating technologies throughout the semester.

General

Understand the **limitations of traditional**, non-integrated design (solutions).

- Facilitate an environment that prioritises working on **common goals** over **individual goals**
- Establish **trust** among participants (open/non-judgmental/sensitized/willing/etc)
- Allow every participant to understand what's **important to the others**.
- Explain the **process** each participant (group) typically goes through, in order to derive their desired **output**.
- Understand **why** we often see things **differentl**y, and
- develop a **common language** that cuts across discipline silos (metaphors/analogies/co-experience)
- Call students '**designers**' **rather than architects** and **engineers**. Engineering should empower architecture and vice versa
- Set **common targets** and instil a sense of joint ownership … and
- introduce a sense of **shared responsibility** across group participants
- **Knowing in action/heuristics**: discuss and advance integrated design solutions on the fly…
- **start with** educated guesses/**rule of thumb**, **then verify** validity of assumptions for preferred solutions

Focus on Performative design

- Address **environmental** building **performance** systemically across Arch and Eng
- Establish joint environmental **targets** per relevant building type à apply end-use performance metrics
    - What are the mechanisms to address them in **early**-stage design?
    - What are the mechanisms to address them in the **advanced** design stages?
- Develop an iterative Arch/Eng process for **optimising performance** (Optioneering)
- Search for integrated design responses to human **comfort** and environmental **loads** à understand how various aspects of the Arch and Eng design are connected.

- Search for **synergies** via design **innovation rather than** relying only on **mechanical** solutions (passive over active) … as part of that…
- foster **multi-functional design** – design elements in an integrated design should be doing more than one thing at once (at least 3 things).
- **Define** the **characteristics** that represent the '**integratedness**' of a design solution. That's what the success of this project should (also) be measured against!

3.2 Schedule for Interdisciplinary Engagement

The studio tutor proposed a detailed IDS schedule in week two of the semester, based on their experience as design studio leader within a 13-15-week semester, as well as preparatory conversations held with the industry advisors and the academic participants. The schedule addresses the output requirements typically inherent to Masters-level design Studio teaching at the Melbourne School of Design, and the specific IDS output requirements for exploring novel technologies to support a Net Zero Carbon design goal. In particular, the schedule maps out the intensity and duration of engagement between the architecture students, engineering students, the regular architectural and engineering industry advisors and guest consultants.

3.3 Weekly interaction between Design Studio Participants

The LXRP Transport Buildings IDS follows an adaptable format of bi-weekly 3-hour online workshops in order to achieve ambitious integrated designs at industry level quality. Studio participants have formed 4 teams of 3-4. The one engineering participant is in a team with 3 architectural participants, the other teams are made up of architectural participants only.

The studio leader presented a clear structure for the project following a design 'discover, define, develop and deliver' format, aligned with the 'Double Diamond' representation (Design Council, 2003). The first four weeks focused on design discovery, prescribing a team exercise of site analysis and independent case study presentations. These tasks were completed in tandem with weekly industry advisor knowledge sharing, providing key guidance regarding infrastructure/ station typology, structural/ construction considerations and designing for sustainability targets. In the fourth week the teams proposed initial design strategies. The studio leader structured these presentations as 'pin-ups', where one team presents to all participants and advisors for 10-20min, sharing presentation slides on Zoom, and then receives feedback in a round-table discussion format, referencing a Miro board of the slides, for a further 10min. The feedback discussions have been observed to be very fruitful, using digital annotation tools and precedent research to discuss the strengths, weaknesses and opportunities of the scheme across the range of disciplines present.

The following two weeks, building up to the mid-semester review, focused on design development. The studio leader structured this phase through alternating workshops of practice pin-ups and team 'break-out' sessions. The 30min break-out sessions provided each team with detailed review and collaboration opportunities with each of the architectural and engineering (structural, construction and sustainability) industry advisors. This iterative process appears to effectively facilitate rapid design development where the break-out sessions allow dynamic ideation and innovation, and practise pin-ups prompt refinement and documentation for presentation. It has been observed that the documentation is a surprising exercise in interrogating design decisions as the development of section and perspective drawings literally provide new perspectives. The first formal presentation of design concepts occurred at the mid-semester review in week 6.

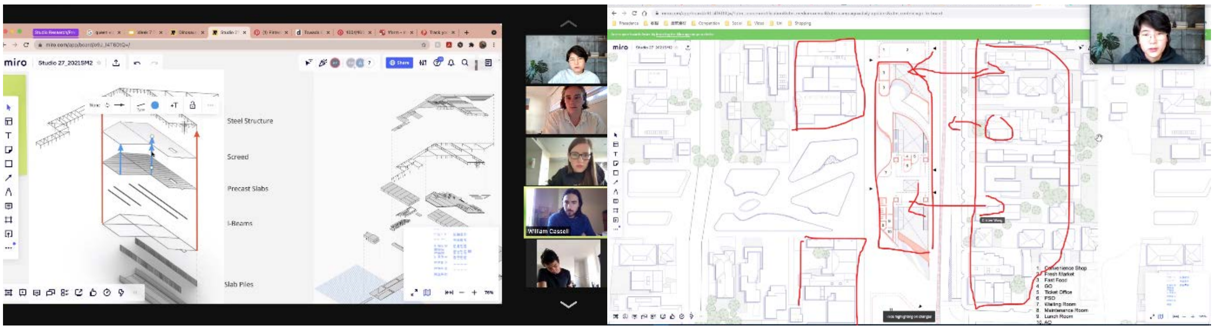


Figure 2: Examples of annotation-assisted feedback in (a) practise pin-up and (b) individual advisor guidance session.

Following the mid-semester review, the design teams undertook rigorous refinement and development based on the critique from key stakeholders. Over the two weeks after the mid-semester review, the design teams iterated design concepts to advance their schemes towards final detailed design. The final four weeks focused on documentation and delivery of the schemes where the design teams developed intentional communication tools, including technical drawings, diagrams, and perspective images, to communicate their schemes to the client representative and other stakeholders at the final review.

3.4 Impact of COVID-19 on Semester Planning, Level of Engagement and Studio Outcomes

This semester has occurred within a stage 4 lockdown for the state of Victoria; therefore, the studio is taking place on-line, using Zoom (video conference software) as the platform for the bi-weekly three-hour workshops and the online Dashboard Miro (a visual collaboration software) as a flexible ideation platform for groups to work privately between workshops and to present pin-ups to the studio. The online format runs smoothly, in part because, after 18 months of restricted access in Victoria, the studio leader, participants and advisors all have high levels of literacy in these digital tools. This has been observed to include presenting dynamic digital models and animations, annotating figures while providing feedback and sharing new ideas and precedents on the go. There are some challenges, particularly in the first four weeks of the studio, where social bonding between the participants was slow. However, over time the social connections have strengthened and as a result peer-peer feedback is occurring more often. It is not expected that the online delivery method will have a negative impact on the project outcomes.

4. DESIGN STUDIO FINDINGS

4.1 Dialogue for interdisciplinarity

One valuable insight taken from IDS studios is the power of visual communication which can be understood universally across disciplines. It is observed that visual forms of communication, such as photos, process diagrams and graphical data, are effective in sharing a concept or narrative.

In practice pin-up presentations, the design impacts of sustainable/engineering features are much more easily understood by advisors when plant and structures are integrated into perspective and elevation drawings (figure 3(a)). This form of communication draws the technology into the conceptual narrative of the scheme and demonstrates, to the team as much as the advisors, the design impacts of engineering features. It has been observed that sometimes technology such as PV solar or materiality is annotated in plan drawings but not integrated into perspectives such that the features are not integrated into the narrative.

Another observed moment of visual communication is the use of diagrams to explain a logical design process, for example the impact of structural layout on circulation or sightlines (figure 3(b)). This universal visual communication develops progressively over time. First, the team shares respect and understanding for specialised knowledge and language. This was an early focus in the IDS through knowledge sharing presentations and feedback on industry standard drawing convention but is not sufficient by itself. The most effective integrated designs then create a unique shared diagrammatic language which supersedes any one discipline, allowing emergent ideation to occur.

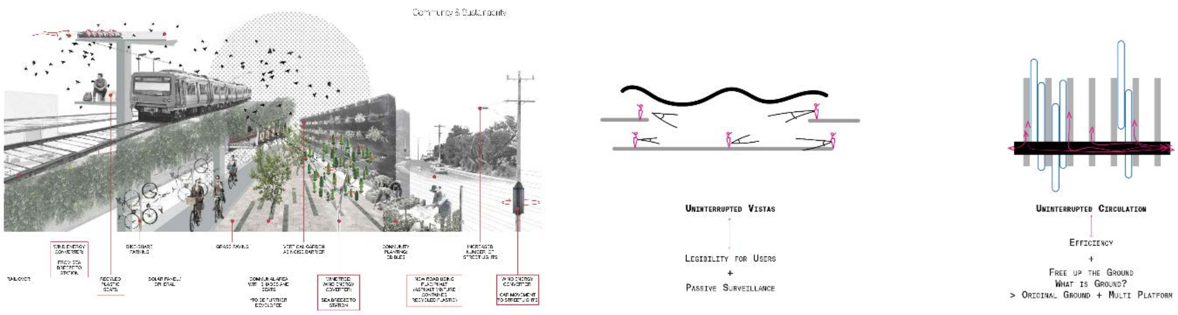


Figure 3: Examples of visual language, (a) annotated perspective with integrated technology, (b) diagrams of architectural and engineering design implications.

Intentional language has been observed to be particularly effective in facilitating an interdisciplinary dialogue of integrated design. Key themes and terms were actively introduced by the studio leader and industry advisors early in the project.

In a knowledge sharing presentation in week 4, the sustainability consultant introduced the term, ‘future-proofing’ as a high-level theme of sustainability in line with the client’s Net-Zero Carbon 2050 target. In the following weeks it was observed that many teams took up the narrative of adaptable and resilient infrastructure that contributes to the community beyond its immediate use. Examples of future-proof design include heat refuges, water collection and drought-resistant native vegetation. Sustainability can be an overwhelming concept for participants and this re-framing of the client priorities engaged all participants in the integration of these features. Participants began to consider the implications of technology on the user experience and focused their engineering responses to those that are tailored to the typology and context in question. Further, this pulled different features of a scheme into a cohesive narrative for presentation to the client representative and industry advisors at the mid-semester review.

Another key term facilitating integrated design was introduced by the studio leader in second week of the project, ‘issues and opportunities’. Initially used to frame the site analysis exercise, the structure of issues and opportunities has continued to guide iterations through the design development phase.

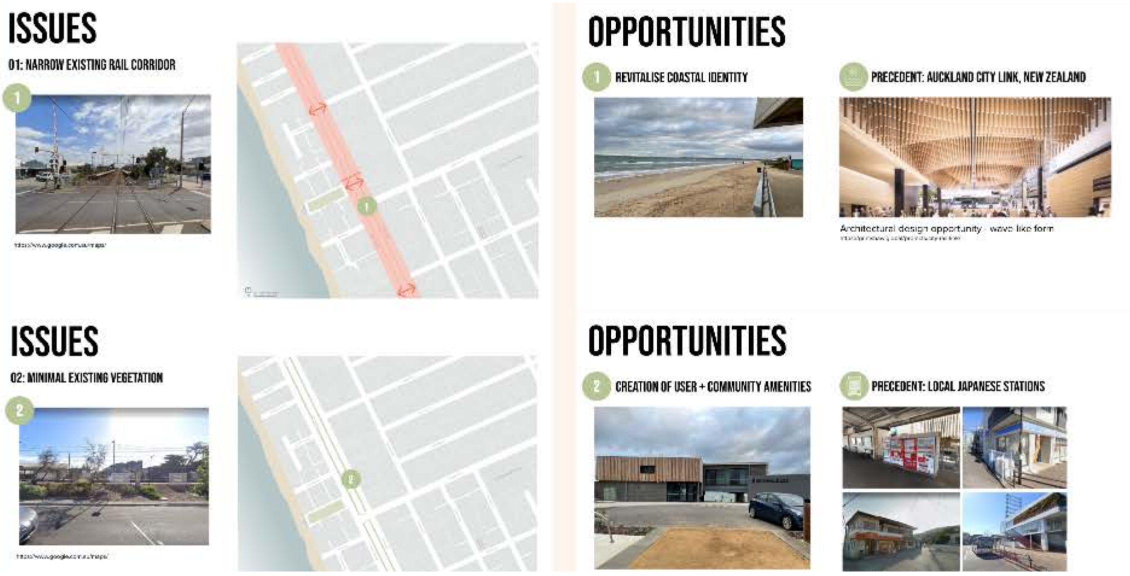


Figure 4: Examples of the use of intentional language ‘opportunities and issues’ in site analysis presentation.

Most teams utilized issues and opportunities in the site analysis to assess the different station locations and the implications of station typology in the community context, as shown in figure 4. The effect of exploring the site within this framework was the introduction of a strong set of goals to respond to in their schemes, for example extreme weather, passive surveillance and active recreation. This provided a strong foundation to later interrogate design iterations and has been observed to be a very effective structure in guiding participants through the scheme development. The language of issues and opportunities returned in weeks 5 and 6, the development phase. In both practise pin-ups and break-out sessions, advisors were observed to interrogate schemes through the question “is this response creating a new issue?”, for example subterranean civil circulation may solve the issue of pedestrian safety from cars but creates new issues such as crime prevention, lighting and costly earthworks. The early integration of engineering insight provides opportunities to optimize the efficiency of a scheme across a range of client considerations.

In the final ‘delivery’ phase of the studio, documentation of designs was shown to be critical, not just in communicating the scheme but also in analysing the function of the scheme from multiple perspectives. For example, moving from designing in plan or 3D models to drawing sections and elevations demonstrates the impact of the structure on the community and environment. This observation highlights the importance of documenting throughout the iteration process and not delaying this till the final assessment or presentation. Further, it was observed that some teams initially struggled to communicate their design to stakeholders and clients that do not have an architectural background, presenting the scheme in a design chronology structure, rather than from the framing of an end user or the client's desired holistic outcomes. This is an opportunity for the education of both architects and engineers to include intentional communication skills to non-technical stakeholders and clients.

It was highlighted in break-out sessions with industry participants that sustainability outcomes are most effectively communicated to stakeholders when they are intrinsic to the overall narrative, with synergies throughout the infrastructure rather than as a list of individual elements acting in isolation. Sustainability should be understood to be more than environmental impacts, reaching broadly across social, health and economic factors. It was observed that some design iterations reduced sustainability to the annotation of bike lanes, landscaping and solar panels on a plan drawing. These isolated elements are difficult to justify from a client perspective if not integrated into the scheme. Rather, a holistic narrative where sustainability is intrinsic to the function of the scheme, benefiting the health of users, economy of the community and resilience of the surrounding ecosystem, is both more convincing to the client and more difficult to reduce/remove in cost analysis. This observation indicates that sustainability outcomes should be defined and targeted early in design, with regular alignment checks and rigorous critique of the success of the project through to producing visual and verbal presentations for final delivery.

4.2 Sharing a set of goals

The concept of sustainability can be an accessibly pathway to integrated design, as a sustainable strategy crosses multiple disciplines and design responses can be technological, passive/spatial or behavioural. An early set of goals that centre around sustainability frames the design iterations of a group throughout the design process and provides many opportunities for integration.

It has been observed in the IDS that teams with an early goal of sustainability more easily integrate engineering practise into their design through energy modelling, civil considerations, and material choices. Conversely, when sustainability is not included in the early design strategy, any sustainable features are not integrated but rather inserted, making them vulnerable to removal through iterations and creating a disjointed holistic narrative. Industry participants highlighted existing benchmarks, such as Green Star and WELL, that deal with social, personal, and economic sustainability as well as environmental sustainability. The use of these existing benchmarks would be useful in early-stage concept design or brief development to focus design teams in on holistic outcomes in their designs and tell convincing narratives to non-technical stakeholders.

It is important to associate such goals or strategies with quantitative targets, for example the Victorian Government's 2030 carbon reduction target or 30% or a self-defined 60% reduction in station energy demand. High-level quantitative targets associated with conceptual strategies encourage integration between architectural narratives and engineering analysis, giving strong grounding to sustainable design responses when interrogating iterations with advisors.

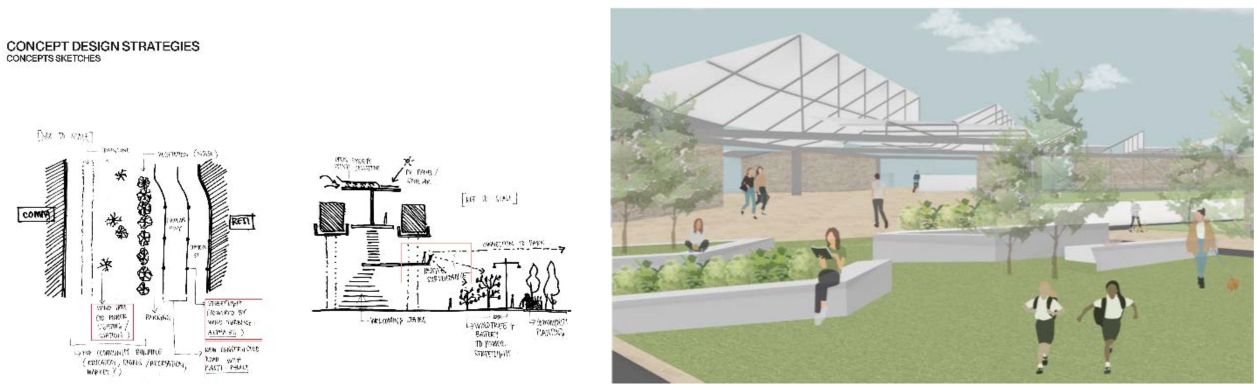


Figure 5: Examples of integrated design strategies, (ab) free-hand annotations integrating sustainable features, (b) structural design in digital render.

In this IDS, a shared collection of goals has been observed to consist of additional aims and priorities to the brief which form a cohesive narrative or strategy. These shared goals are most effective when clearly defined and agreed upon by a team in the 'define' phase of design, aiding co-authorship and collaboration within the team and guiding future iterations.

It has been observed that the studio leader's focus on the design strategy for the first three weeks facilitated goal setting within the teams. The key to this process was the delay of any architectural massing so that teams are not distracted by their preconceptions but rather undertake intentional research and gain a realistic and comprehensive understanding of the conceptual brief. The type of goals set should surpass any one discipline and strongly align with the client's priorities. In this way the narrative of the scheme can clearly target client desired outcomes, justifying design decisions. Further, if the client's holistic priorities are understood, through integration, it is possible to challenge conventions in design decisions as the team is targeting outcomes rather than specific elements in the goals. An example of this was a team that placed, at the heart of their conceptual narrative, a wetland ecosystem. This resulted in a design that produced positive social outcomes through recreation and connection to nature rather than through conventional commercial retail.

The most effective goals in this IDS are those that are holistic and pertain to the contribution of the infrastructure to the community, rather than specific features or an aesthetic. The designs emerging from a strong set of goals have been observed to be adaptable and flexible. Any single feature is one of the infinite potential responses and can therefore be interrogated and curated in break-outs without the team's ego halting iterations. This was demonstrated when an advisor asked, "What other program or feature could achieve the same goal?", prompting open-minded innovation rather than resting on convention.

4.3 Perspective and process

An informed and intentional process can make a significant difference to the level of 'integratedness' of a project or team, the conventional system or hierarchy of design teams will only constrain the extent to which integrated design can optimize and innovate. The most effective shifts in paradigm observed in this IDS are moving from knowledge to practise and from insertion to integration.

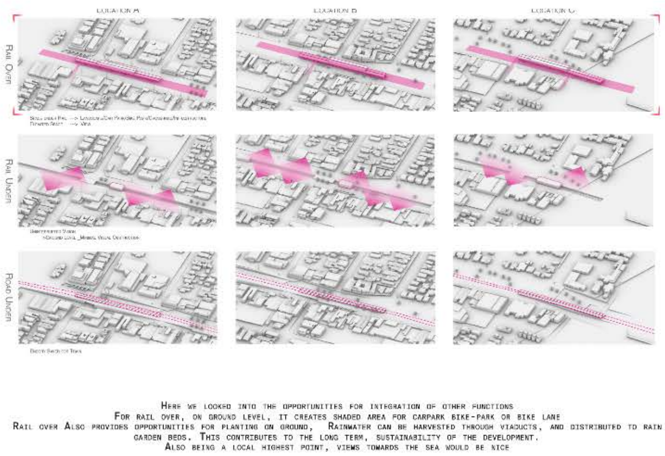
In the conventional design process, the role of any engineering designer is to validate architectural design concepts with specialised knowledge, whether it be structural, electrical or mechanical. This engineering validation acts to document architectural design, not drive it. However, it has been observed that the most valuable shared attribute of all engineering specialties is the practice of systematic analysis. The process of rigorously defining criteria, simulating potential scenarios and exploring the results with some level of objectivity can lead to optimized and unexpected results. This was observed in early geometry development, where traffic analysis drove different iterations of road alignment and consequential master planning, as shown in figure 3(a).

Figure 6: Examples of analysis driving design, (a) traffic simulation, (b) rail alignment.

TRAFFIC ANALYSIS

Level Crossing Removal

From link	To link	Travel time(s) (level crossing)	Travel time(s) (proposed)	Travel Time Reduction (%)
Nepean Highway/Fraser Ave	Nepean Highway/Rae Rd	29	29	-
Nepean Highway/Fraser Ave	Edithvale Rd	66	46	30%
Edithvale Rd	Nepean Highway/Fraser Ave	47	18	60%



This concept was developed further when the criteria against which scenarios were being tested included architectural logic, achieving particularly engaging integrated results. This occurred during the concept strategy pin-up in week four for the assessment of rail alignment options, where a team applied testing criteria including both engineering and architecture priorities to the matrix of options (figure 3(b)) in order to select an emergent optimized solution across the disciplines. This idea of engineering practice as a process rather than a library of knowledge continues to be explored and can be applied at multiple points through the IDS so long as the conceptual strategy is clear and flexible.

One limiting feature of the studio process was observed to be the documentation for assessment in the final four weeks. Due to the requirements of the studio as an architectural subject with conventional assessments, design iterations had to be finalised at the 75% milestone so that there was sufficient time for design teams to produce industry-level technical drawings and supporting presentations. This is a critical skill for all designers to have, regardless of architecture or engineering backgrounds, as if you cannot communicate the design to a client, it will never be implemented. However, the architectural focus of this communication, constrained by the assessment requirements, limited the level of integration able to be achieved and, in some cases, disregarded the sustainability outcomes as superfluous.

The process of integrated design requires intention and engagement from the project inception to develop a resilient and efficient design. One key insight from the IDS is the distinction between 'inserting' features and 'integrating' responses in a design scheme. This system of inserting in contrast to integrating has emerged organically from observation and was not introduced by the studio leader or advisors.

Integration occurs most effectively when sustainability and engineering are integrated into the design at multiple scales: this was observed when a team 'zoomed in' from the master-planning of encouraging active transport, to the detailed scale of façade finishes and natural ventilation. This shifting scale of sustainability creates a holistic narrative that is compelling from a client perspective, avoiding individual isolated 'inserted' sustainability features.

It was observed that some teams defaulted to inserting features when sustainability was a late consideration in development. This was observed in week 5 where one team focused their sustainability strategy on timber cladding for their platform, an inappropriate material for the fire rating requirements of rail infrastructure. This feature of the scheme was challenged by advisors experienced in the rail infrastructure context and therefore was removed in following iterations. In this case sustainability was literally 'slapped onto' the design rather than intrinsic to the narrative of the scheme and was a valuable lesson to the importance of intentional and early integration.

It is interesting to note the importance of materiality as a nexus for sustainable design integration, generally for construction and structural engineering, and holistically intersecting with sustainability. One example of materiality as a nexus occurred when a team explored changing material from steel to timber as a way-finding tool and in compliance with fire safety and structural requirements for train stations, reducing the embodied carbon of the scheme where possible. As the user moved from the beach-side park with canopied market stalls (CLT structure) to the urban context of the train station building (steel structure) materiality influenced the architectural language as well as the construction and sustainability of the infrastructure. In contrast, a team that only considered materiality through an architectural lens had poor sustainability outcomes, using a large volume of concrete with aluminium cladding. This demonstrates how material selection is an opportunity but also, if sustainability concerns are overlooked, a high-impact decision in terms of sustainability outcomes.

An example of successful implementation of an integrated process was observed in one team's discussions of their structure system in week 4 during a break-out with a structural engineering advisor. This was the first architectural massing iteration following the design strategy pin-up. By literally framing their design early in the development process, the structural engineering has acted as the spine of their design, holding together the adaptive and dynamic iterations in the following weeks. Further, by having a strong and integrated structural concept of a steel truss spanning the rail (figure 5), they have been able to interrogate and optimize the system in subsequent iterations.

4.4 Collaboration with confidence

It is paramount that an integrated design team is a safe space where innovation and experimentation may occur in collaboration, built on strong social connections. Without these foundations the convention of design team hierarchy results in a serial structure, where engineering follows architectural design, validating and documenting but not sculpting or motivating a scheme. For this reason, most engineers shy away from open-ended design problems and experimental ideation for fear of critique or negative feedback and want the security of clearly outlined problems.

This established hierarchy can make integration through inversion challenging, demanding a large shift in paradigm. One observed alternative to inversion is iteration, explicitly introduced by the studio leader in the project brief. Iteration initially appears to follow the serial relationship of convention, however, rather than validating a fully detailed design, iteration creates a feedback loop of analysis and experimentation. The engineering contribution to early-stage iteration has worked effectively using simple "rules of thumb" for example load flow, column spacing and construction impacts (figure 7(b)). A level of discomfort is still observed as engineers continue to want more finalised information before giving a solution but with relationships based on confidence and trust, integrated schemes are developing.

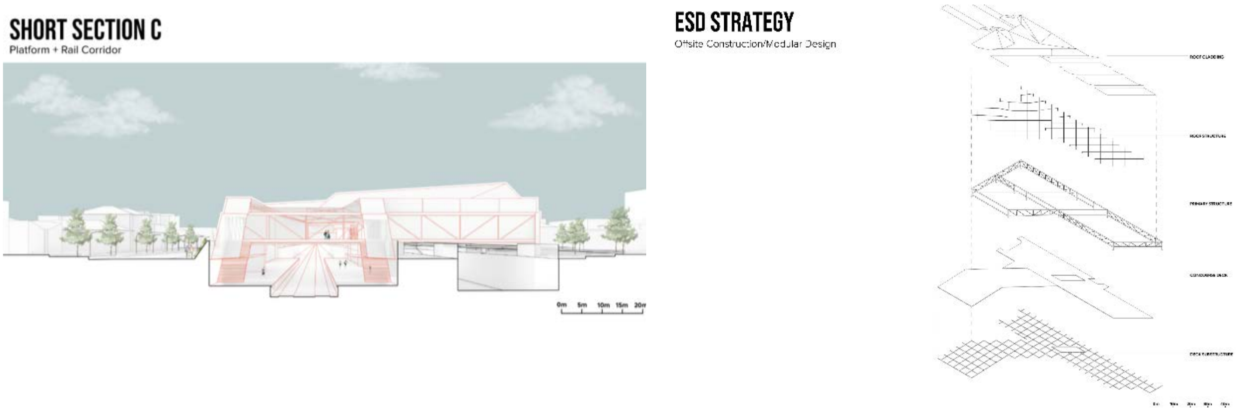


Figure 7: Examples of integration of structural design at mid-semester review (a) section drawing, (b) exploded isometric drawing.

An emergent insight as the semester progressed was that a designer with some level of experience in a discipline that differs from their primary discipline is both motivated and confident in integrating the two disciplines. It is interesting to note that the cross-disciplinary experience does not need to be comprehensive, rather a broad appreciation is sufficient to facilitate integration. In the studio it was observed that someone with cross-disciplinary experience could be more effective in contributing to an integrated design than the integration of a designer with one new speciality. One explanation for this is that the appreciation of multiple disciplines allows a designer to build connections and pathways to integration actively, rather than providing speciality design without the experience to weave it into the scheme. This indicates that, moving forward, all members of a design team should have exposure to multiple disciplines in the education phase of their careers so that everyone shares the responsibility of integration.

Along with confidence, empathy and social connection are important attributes in a successful integrated team. A socially connected team tends to have greater resilience and adaptability in the face of critique compared to a team delegating and working independently.

An example of the relationships in a socially connected team are shown in figure 8 where a design participant reflects on their team dynamic, and the lessons shared in terms of technical skills and conceptual development. The outcomes observed suggest social connection and empathy help to integrate design by removing the ego of participants so that they are less precious about their iterations and more open to critique, allowing ideation and experimentation to occur freely, guided by the shared set of goals.

Furthermore, empathy and respect in a team opens discussions up so that contributions from all team members are engaged with, not just positive or agreeable feedback. This relationship-building takes time, particularly in the format of online workshops and within the hierarchy of university participants and industry advisors. Some teams still respond defensively to tough feedback. In general, as the studio progressed, the social connections developed progressively between design teams and industry participants. As this occurs the specialist advisors are trusted and understood as drivers of design rather than judges, developing designs and providing specific contributions rather than general advice. When this was not the relationship, design teams were overwhelmed and confused by contradictory and varying advice, disregarding feedback that was challenging. Over time, an appreciation for collaboration emerged, allowing the schemes to be moulded and refined rather than thrown out and restarted.

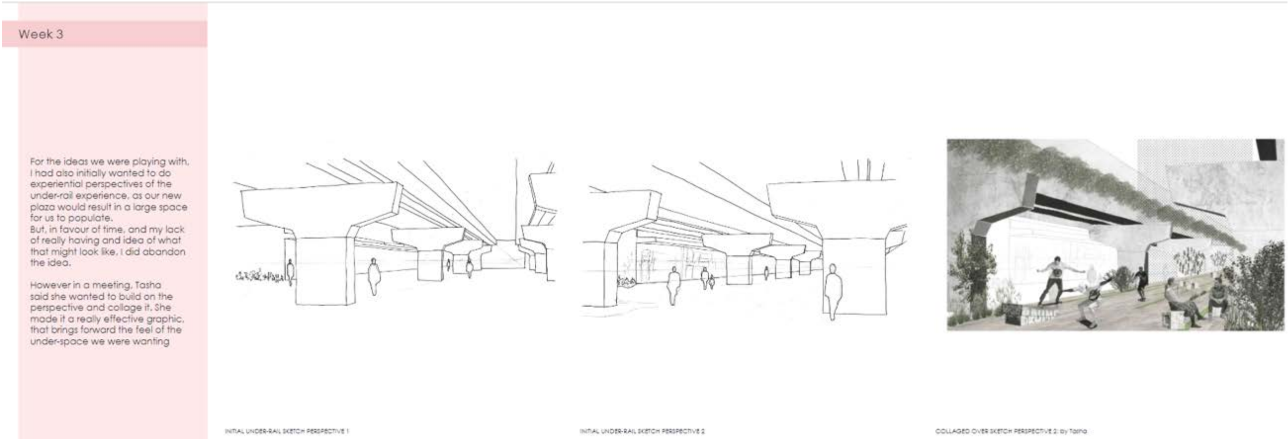


Figure 8: Example of reflective journal where participant discusses the team dynamic and the effect on drawing outcomes.

4.5 Feedback from the industry participants and the studio leader

The feedback from the key contributors to IDS-06 was captured via online video interviews. The studio leader, 4 architectural industry participants and 2 engineering industry participants participated in these interviews. The interviewees were asked about the drivers of integration in the studio, the role of the brief and structure, the successes and challenges and any insights into integration in industry. The feedback is summarised below, providing valuable insight into how integration impacts studios and industry projects.

The design brief was deemed by most key contributors as inherently integrated because of the challenging linear infrastructure typology in question. It was highlighted that a rail alignment and transport building scheme demand rigorous engineering requirements for safety and security, for example the services required for train signalling dictates the rolling carriage envelope therefore the elevation of the built form. One contributor observed, “it's a project that inherently requires a lot of particularly structural input.” Further, the position of the client as state government sets the design life, and therefore structural demands, very high.

While the typology facilitated integration, it was found, due to the position of designers as university students without extensive professional experience, that it was challenging to innovate on the engineering requirements of the infrastructure. This was proposed by some contributors that this was due to a lack of confidence in foundational knowledge, whether that be structural, rail engineering or environmental design.

One surprising outcome of the brief was noted in interviews, there was an integration of urban planning and landscape design “beyond the site boundary”. Designers were ambitious with community value and developed narratives that demonstrated the impact of the rail infrastructure on the wider community.

When considering **the key sources of design inspiration** there was consensus across the key contributors that most of the design inspiration for the transport buildings and associated infrastructure were based on responses to “issues and opportunities” such that outcomes were “emergent”, driven by community history and physical site. It was noted that this could be attributed to the brief and client priorities being focused on adding value for a specific community and location. Another source of this design process is the architecture firm participating in the studio, COX Architecture, who, one key contributor noted, often find inspiration through “a deep understanding of site”. This aligns with the insights and outcomes of the studio.

One notable observation about the design approach being “emergent” was that, for some designs, this can result in a shift in focus away from sustainability outcomes, particularly for embodied carbon of materials. It was suggested in interview that this could be solved by assessing design iterations from an engineering or environmental design perspective, asking of a scheme’s elements, “Do we need it? And then doing it, and how big does it need to be? And then, does it need to be made out of this?” These relatively simple questions can challenge architectural convention and re-frame the value of a design in the interest of both sustainability outcomes, client priorities of cost and impact, and potentially create some intriguing architectural abstractions. One key contributor commented, “It would have been intriguing if someone had pared the station back to minimalism – just less.”

In interviews an experimental source of inspiration was suggested as being an interesting innovation, this was to explore precedent- a conventional architectural source of inspiration, in the context of integrated design specifically. One key contributor mused on this, could we study specific historical integrated design partnerships or teams and extract some abstracted design processes from this? Or analyse “an engineering aesthetic” to abstract design concepts from engineering disciplines. These innovations in inspiration could be explored in a future program.

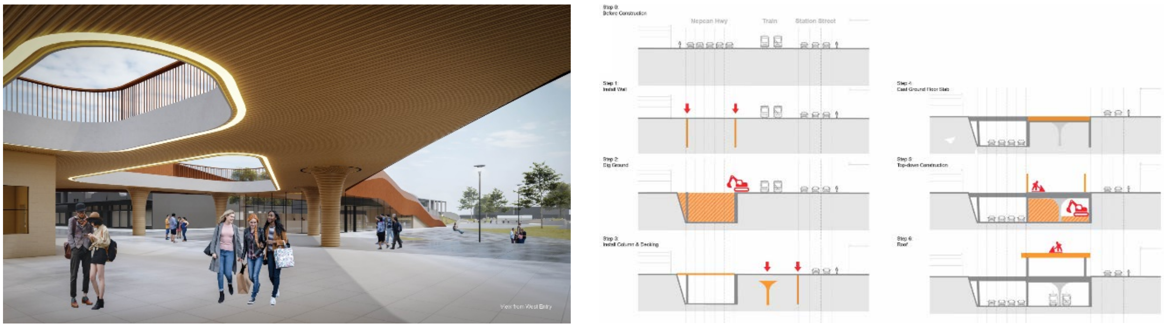


Figure 9: Example of final design documentation (a) perspective, (b) construction staging diagram.

The concept of **design co-authorship** and the extent to which engineers contribute to authorship was a topic of varied opinion in the studio contributors. One common theme of engagement and authorship was that, without intentional facilitation, authorship is quite dependent on the personality of the designer. A common difficulty that was discussed was that some engineers experience a lack of the confidence required to challenge design decisions or to share experimental ideas. This obstacle can be overcome at the education level or by including a “integration facilitator” in design teams to encourage all members of a team to co-author, regardless of personality types. One key contributor noted, “engineers and architects get the best outcomes when they're actually really closely integrating with each other and challenging each other all the time.”

Considering design co-authorship within the studio teams, one insight was made for future improvement, “[It is] critical to run it with everyone with the same skin in the game.” The structure of this studio was that the architecture subject had double the weighting, in terms of assessment, compared to the engineering assessment. This observation highlights the importance of sharing responsibility and accountability for a project across a team, reflecting a greater problem in industry where there is still a strong hierarchy of design authorship through design team, inhibiting co-authorship and therefore integration. In future programs an improvement could be made to the structure of the assessments such that goals and accountability were shared across design teams.

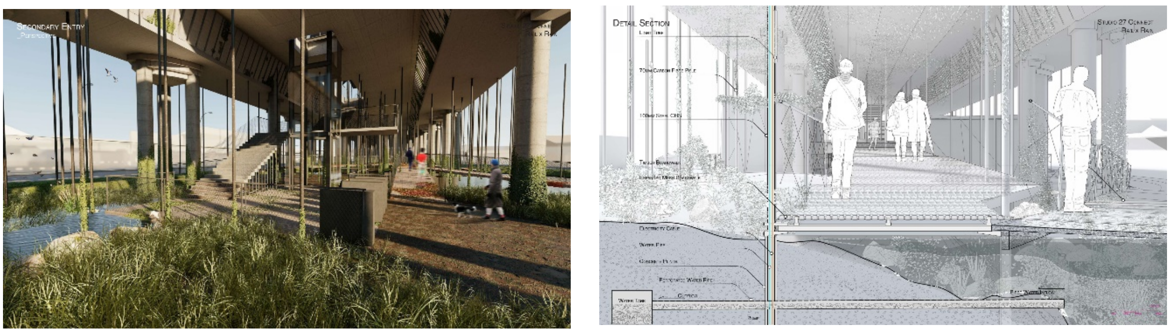


Figure 10: Example of final design documentation (a) perspective, (b) drainage system diagram.

When asked about the **impact of the timing of the collaboration** on integration, the key contributors provided compelling responses that indicated the significance and challenge of timing integration. Consensus was shared that the regular exposure to engineers from industry from the inception of the studio was a new and significant experience for the architecture students participating in the studio, where the contributions were “early enough for them to digest over time and also to develop through design stages”. In the first four weeks of the studio, the industry contributions were content focused, presenting technical knowledge and considerations specific to the typology for the designers to use as the basis for their initial design iterations. One key contributor commented that it would be interesting to introduce lectures throughout the project where industry participants advised on possible design approaches, how to iterate and innovate, to facilitate refined integration, **"**so you would have a lecture which would foreground your next moves".

Improvements on the timing of collaboration were highlighted from multiple sources, focusing on the feedback sessions. It was noted that the design teams seemed to get overwhelmed when they received a high volume of feedback from multiple sources, resulting in some considerations being disregarded in iterations because there were too many different design drivers being suggested. One contributor commented, "you can only pull so many levers". This indicates the importance of intentional focuses through the design as well as regular exposure to all design disciplines. This was particularly evident with the environmental design feedback, and it was suggested to introduce "scoping workshops early with measurable sustainability goals" to provide more accountability for sustainability outcomes.

The general response discussing the **successes in the studio** was that the students developed schemes at a much more refined level than comparable 'un-integrated' studios by simulating an industry design team rather than working as individuals – as is convention in university studios. This team-approach was the chief strategy in balancing concerns and producing strong final schemes and is an important lesson for future programs. It was observed that the most integrated outcomes came out of strong early design concepts and associated goals, this allowed iterations to refine over time, balancing interdisciplinary considerations, and be self-critiqued against the early intentions.

Another highlighted success was in the communication skills developed by the design teams. Key contributors commented on the shift from an architectural style of communication to a more holistic narrative and presentation approach, because of the inter-disciplinarity represented in the regular feedback sessions. Balancing architectural and engineering concerns often came down to the narrative with which the design was communicated, therefore, developing a holistic narrative, that can be engaged with by a "lay-person" was an important re-framing of design decisions.

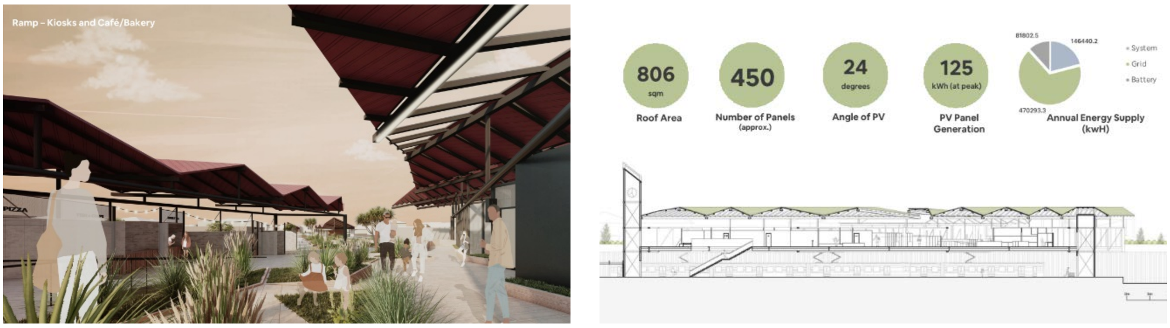


Figure 11: Example of final design documentation (a) perspective, (b) energy generation diagram.

The **most significant challenges** when iterating towards more integrated and sustainable designs were observed to be confidence in conceptual knowledge, defining sustainability goals and balancing assessments with innovation. A recurring theme of the observations from the key contributors was the importance of "fundamental knowledge" and while considerable time was spent on presenting accessible 'rule-of-thumb' technical content early in the studio, this was still a challenge for design teams. Whether it was focused on structure, construction or environmental design, there was a large volume of foundational skills and considerations for the designers to absorb and apply in the brief duration of the studio. One contributor noted "If you haven't been introduced into alternative ways of thinking, then you're going to be pretty limited [in applying them]." This challenge is potentially less of an issue in industry, where specialised technical skills are established, but an appreciation for inter-disciplinary knowledge would be a valuable additional to all design-team members.

Another noted challenge for the design teams was established commitments to goals. Particularly in terms of sustainability outcomes, most design teams struggled to quantify their intentions and aims and therefore could not assess the success of their iterating schemes. One contributor highlighted this issue of "accountability" and noted that commitments to sophisticated and quantifiable goals are key to success in industry. This was built on by another contributor, noting "a good architectural project knows how to achieve its architectural vision or project with the least amount of resources". In the case of this studio, design teams struggled against time pressure and new knowledge to refine their schemes for rigorous and optimized sustainability.

A challenging factor in the structure of the integrated design studios is the role of assessments for the designers and how this impacts the potential innovation and integration that can be achieved. By framing the program from an architectural student designer's perspective, one key contributor commented "they're being assessed as architects, and it was quite hard to get past that". Particularly for the architecture students, they are competing with other studios that are not integrated and so feel the pressure of time to produce high quality documentation for assessments.

The key contributors observed some **barriers to integration in industry**, these were discussed, and potential opportunities were highlighted. Some barriers are shared across university and industry, for example confidence and communication and the pressure of time on deliverables. One key contributor noted this link from university to industry, "students [graduating] should be giving everybody [in industry] a hard time… And then they should be pushing everybody along". Part of a university education should be advocacy for sustainability so that students can enter companies with the knowledge and confidence to challenge convention and innovate through integration.

Another barrier highlighted was financial requirements, one key contributor noted, "in a real project, sustainability comes under fire when cost and time comes on." In contrast to this, however, there are more recent trends for projects to include sustainability and cost Key Performance Indicators (KPIs) or awards to motivate good integration in the competition and delivery phases, whether that be efficiency or reductions in energy or emissions. It was noted in one interview, "if you're well integrated, then things are probably more efficient." This demonstrates that we may see further integration in industry briefs in the coming years.

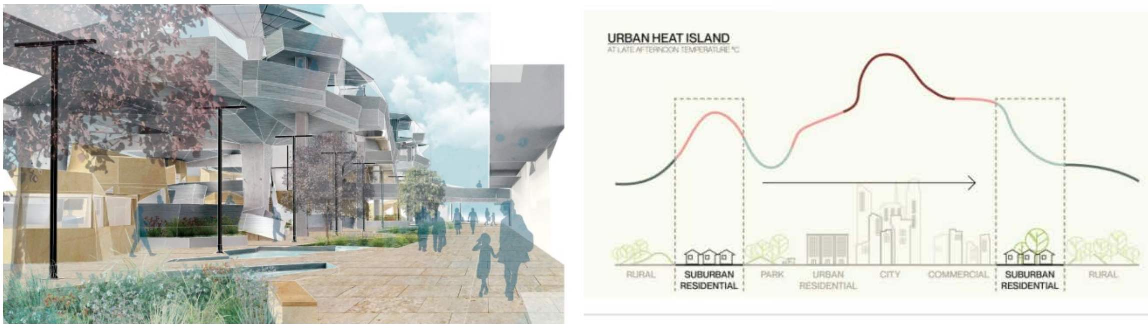


Figure 12: Example of final design documentation (a) perspective, (b) urban heat island diagram.

There was consensus that **this experience was a useful part of students' high education** experience. The learning outcomes for students were the sharing of knowledge between designers, an understanding of the shared responsibility of sustainability across disciplines and preparing them to be collaborative designers in this inter-disciplinary industry. One key contributor noted, "there's students at different levels, and they all can learn from each other." Knowledge sharing between students, rather than from a teacher, can be impactful and nuanced, whether technical or conceptual, both discipline specific and holistic. It was reinforced that this studio provided the students with many important new experiences and skills that they will be able to carry through their education and into their future careers.

Another key value in this studio is that the experience reflects the challenge and importance of sustainability in our industry. One key contributor noted, "all architects should probably do this. We should all have sustainability in the back of our minds… some of the best architects in the world already do all this stuff. They're already having sustainability or at the forefront of all their designs. That's what makes great designs." This shift from silo-ed disciplines to shared aspirations and authorship is critical to holistically sustainable infrastructure design. In discussion of the value of this studio, it was highlighted "sustainability can be radical or humble", the range of designs in this project demonstrated the breadth of possibility when designing to sustainable outcomes.

By creating an inter-disciplinary environment, this studio simulates industry for the students participating. One key contributor commented of standard university studios, "you don't normally learn what to give the engineer to get good input". The nuances in communication between disciplines were discussed as both challenging and critical to achieving efficient and effective design outcomes. This involved both appreciating other discipline-specific communication and sharing a language to collaborate as noted by one key contributor, “it is super valuable to be able to think in terms of both languages, be able to think for speciality and holistically.”

4.6 Feedback from the participating students

There existed a mixed level of experience with environmental design among students who attended this class, with an equal number having had exposure to the topic and those who did not, before starting the IDS.

Students listed: *level of existing expertise of individual contributors,* as the key design-drivers affecting successful environmental design to achieve renewables/zero carbon goals, followed *time assigned to the dialogue between Architects and Engineers,* and *in-depth knowledge of technology for collaboration.*

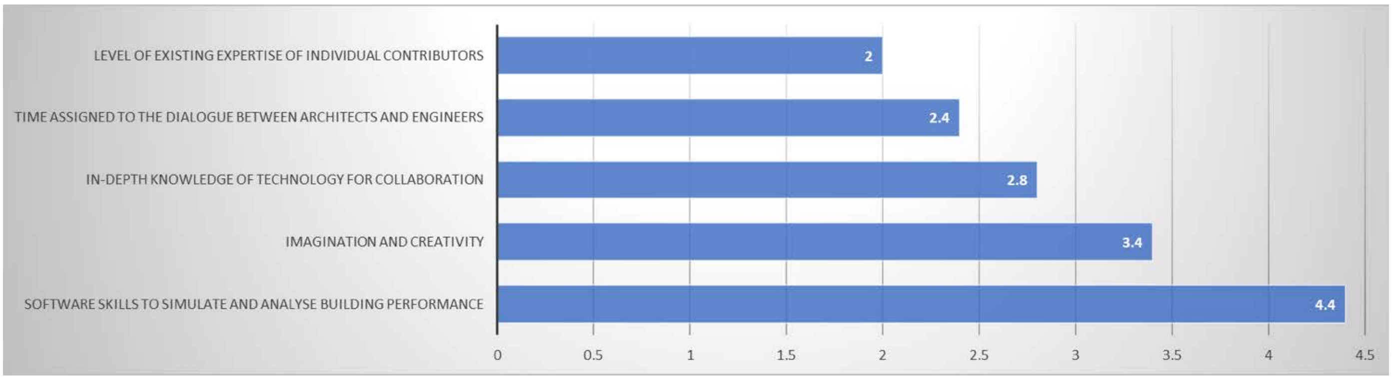


Figure 13: Key design-drivers affecting successful environmental design (with smaller numbers ranking higher)

Overall, the vast majority of participants felt that the client’s brief supported them in achieving a balance between architectural and engineering design, resulting in a median score of 4.6 (out of 5). Participants stated: the brief was clear and easily understood, and the type of brief drove the approach to design. It was adequate as all of the train station design constraints were listed. One student did highlight that: the brief asked us to develop our own solution of ESD and construction stages and the tutors with experiences gave us a lot of helpful feedback.

One voice was critical about the omission of performance benchmarks in the brief suggesting: *the brief didn't say much about things outside architecture, only regulations (ramps, height limits, viaduct widths, gantry heights etc) we needed to follow.*

Prompted about the most critical decision-making points when balancing architect/engineer input for generating environmentally optimised design solutions, students listed:

- *whether the project would be largely investigative/exploratory as opposed to pragmatic - which then determined the level and type of input that went into the design*
- *using some engineering simulation software to test and optimise architectural design ideas*
- *roof design with rainwater collection/solar energy/other*
- *the structural decision on the location and density of random distributed columns for the viaducts and platforms on a wetland. It's an unusual situation, even the design consultant debated it with the structural engineer during class.*

As main inspiration from industry consultants for Laboratory design, students listed:

- *the site and its relevant context, particularly in relation to the potential users of the project*
- *the constraints of the site and the design of a rail station itself*
- *the tutor's suggestion and precedents from the external websites they recommended as reference*
- *group work and tutors' feedbacks!*

According to the students, the engineers contributed to the authorship of design solutions primarily via *consultancy-type feedback, followed by supplying background data and knowledge, and* by acting as co-authors or co-creators of ideas.

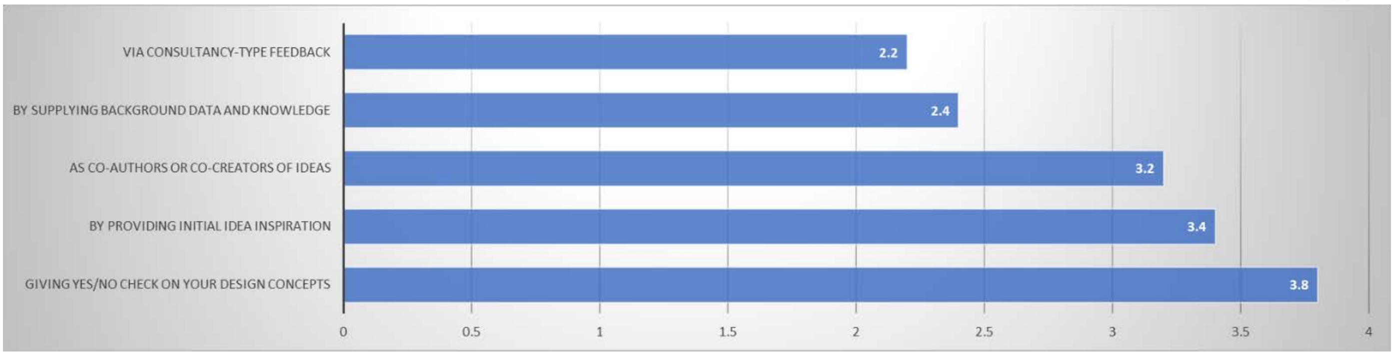


Figure 14: Reflection on input provided by the Engineering Consultants (with smaller numbers ranking higher)

With a median score of 4.6 (out of 5), nearly all students agreed that the input by consultants strongly increased their 'level of understanding of' environmental issues and associated solutions. Overall, students acknowledged the benefits of the integrated design process and the collaboration with consultants as one student explains: *It is worth seeing how they attempt to resolve unusual situations, and how to achieve architectural intent as much as possible. It is kind of useless if engineers are just focusing on things that we already know. Instead of pointing out a structural issue, it's more valuable if the structural engineers can help to find a way of workaround, instead of oversimplifying the project to achieve structural feasibility.* Some students wished for the feedback by consultants to be more targeted, arguing: *It may have been helpful to be able to focus on a specific specialty per class (e.g. structural engineering, landscape, sustainability) to allow for more opportunity for directed feedback, because more specific work could be produced.*

For this iteration of the IDS, students lamented the less-than-ideal collaboration between architecture and engineering students, as COVID resulted in a greatly diminished cohort of engineering students. Only 1 such student ultimately joined this IDS. The quality of collaboration was rated 3.0 points out of 5 (with 1 being best and 5 being worst). One student reported: *Whilst I didn't work in a group directly with an engineering student, hearing about their investigation and research encouraged me to also these aspect beyond my general design process. Overall, the sentiment among students clearly made a case for a better-balanced number of architecture and engineering students*

In IDS-06, only a minority of students sensed that they had to compromise aesthetics and functional design aspects when balancing architectural and engineering concerns (median score 2.2 - with 2.5 meaning '*neither-nor*'). This points towards some evidence that for this studio, the performance focus did not impact the design aesthetics of the project much.

Despite the overall positive feedback about the IDS, students also reported several challenges when advancing their design-thinking with environmental/engineering constraints in mind, listing: 'time constraints on projects, followed by *'knowledge gaps',* and *'education in isolation'* as key obstacles.

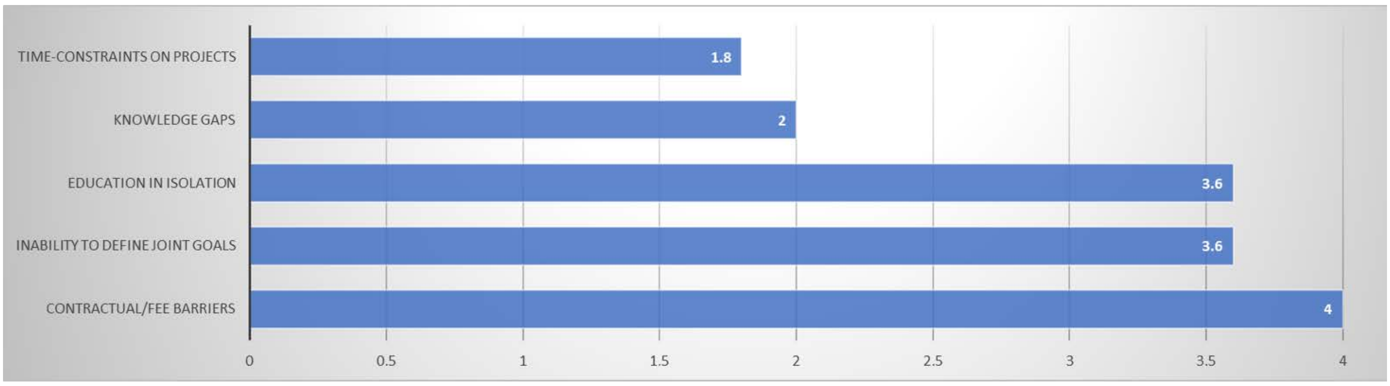


Figure 15: Challenges reported by the students. (with smaller numbers ranking higher)

Additional struggles reported by the students were expressed as follows:

- *Finding a creative and conceptually related solution to the constraints.*
- *Making the structure still appear aesthetically pleasing*
- *Environmental solutions are not specific for our group concept. General solutions that can be applied to any project.*
- *incorporating environmental issues into the overall design*
- *there's not enough time to consider and address feedback from different panels for each week.*

Overall, the introduction to Integrated Design as part of the studio was well received by students with one of them defining it as follows:

- *as particularly relevant and critical to design overall*
- *design/engineering disciplines working together from the very beginning of a project to complete a shared goal*
- *learning a lot from tutors and consultants from various backgrounds in the industry, but not each of the suggestions could be embedded in the final design.*
- *people from different fields collaborate to deliver a project, instead of architecture students worrying about things (too much) outside their field*

The question about the usefulness of integrated design processes as part of their university education, elicited a highly positive response, with over 80% saying it was 'quite' or 'extremely' useful (median score: 4.2 out of 5).

5. STUDIO DESIGN OUTPUT - Select Examples

A select number of 2 group projects (Group 1 – 'Edithvale Exchange' and Group 4 'Uplifting Chelsea') were taken further for feasibility vetting in order to consolidate student feedback and extract some key data. These two station projects allow for a more in-depth exploration of zero carbon initiatives for train-station design and established an Energy Use Breakdown typical for the train station typology investigated as part of this IDS. It is noted that the examples investigated are both located in Melbourne with a predominant mild temperate climate, requiring heating in winter and cooling in summer.

The scope of the students' propositions largely related to material selection for structures with large spans, high-floor-to-ceiling heights and a mix of uses ranging from the train platforms all the way to different retail and transport related functions. In that sense, students frequently had to consider the nexus between functional requirements, aesthetics, structural systems, and energy performance.

Timber seemed like a natural choice for embodied carbon reduction, yet fire safety regulation made its use unfeasible. Energy efficiency, (wastewater) management and carbon reduction, were some of the key concerns investigated by students to see if a zero-carbon target was achievable for these types of facilities. Solar simulation software (such as Ladybug) was used by the groups to conduct shading and sunlight-hour studies. In addition, the more advanced eQuest and EnergyPlus applications assisted with building envelope optimisation, in particular: shading, thermal insulation, skylight area definition and more.

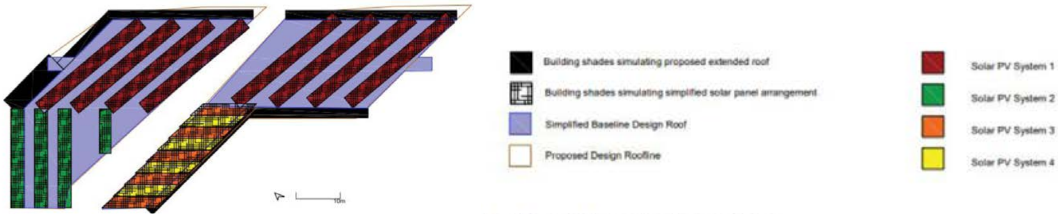


Figure 16: Simplified roof layout for eQuest simulation, Annitta Lin

Within each IDS project, there were many common active and passive sustainability initiatives applied, however each group achieved slightly different and innovative ways to incorporate this into their designs.

5.1 Passive Measures

Some of the initiatives introduced by the students were progressive or innovative and provided some new ways of thinking about and designing transport facilities.

- Optimising material choices
- Rainwater drainage & Collection
- Applying reused and recycled materials
- Optimising façade performance and roof orientation with horizontal extrusions for shading
- Extensive planting/natural vegetation for shading and as thermal buffer

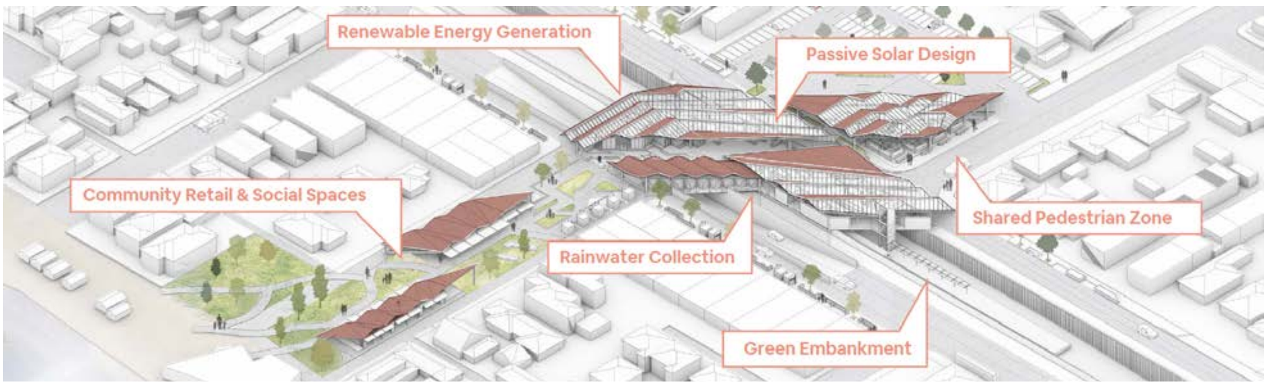


Figure 17: Group 1 – Edithvale Exchange - Project Isometric, Amber Young, Alessandro Antoci, Xiaohan Zhao, Annitta Lin.

5.2 Active Measures

Next to addressing passive measures, a number of active measures were proposed by the two groups selected from this studio. Large roof areas of the stations with up to 2500m2 of surface area did provide opportunity for students to investigate the use of photovoltaics, next to other active measures such as ground coupled heat pumps, wind farming, and Piezo-electricity generation.

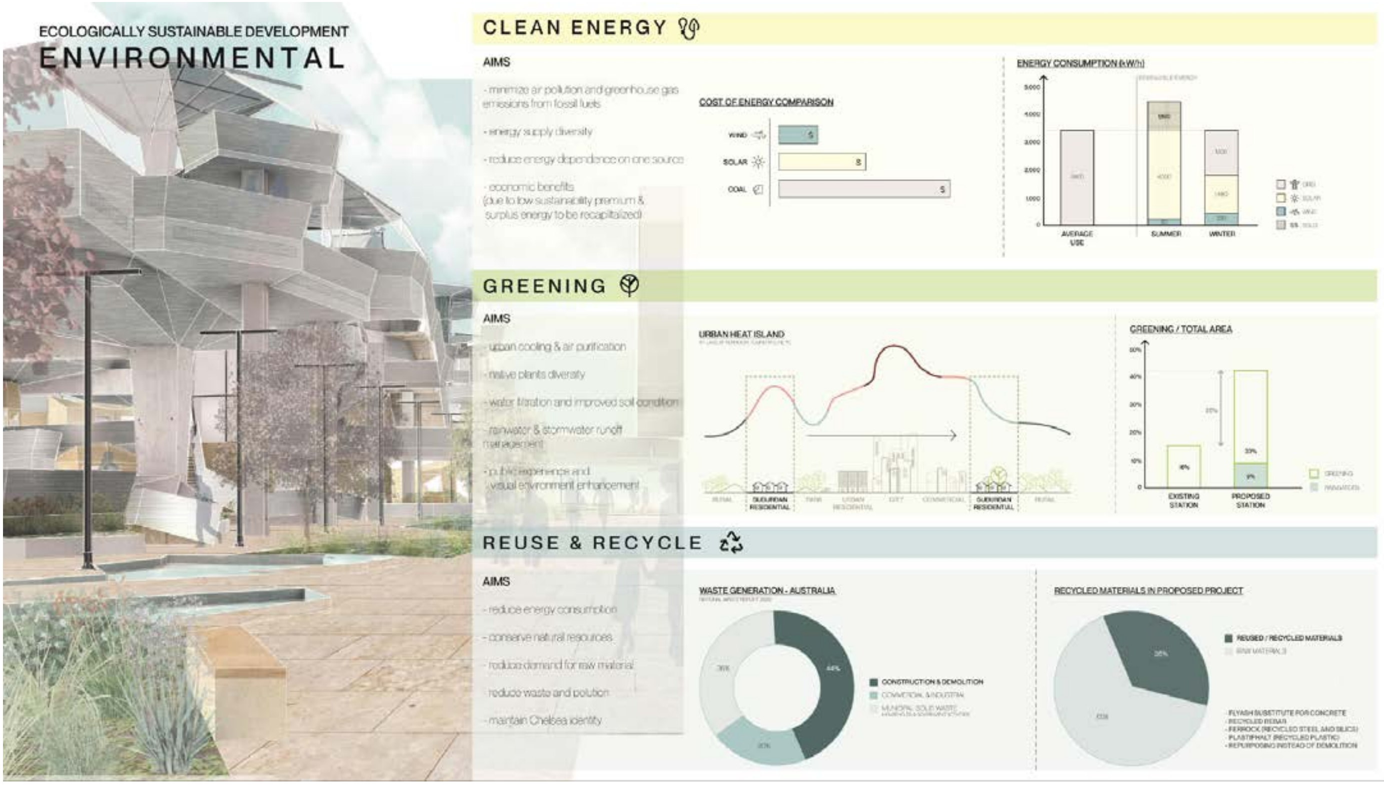


Figure 18: Group 4 Environmental Sustainability Strategy - Chhay Kourng Lay/Aurelia Tasha Handoko/ Charles Ng/Olivia Loh.

Key initiatives can be summarised as follows:

- Photovoltaics (rooftop)
- Ground coupled heat pump
- Wind harvesting
- Piezo-electricity generation
- Battery Systems

Critical review of several suggested solutions by student groups:

It was great to see the variety of solutions suggested by all student groups. They all made efforts to include environmental strategies in their projects with highly engaging visuals to illustrate suggested solutions. The two final schemes selected highlighted innovative solutions to address zero carbon goals among highly diverse mixed-use projects with strong ties between the train-station functions and their surrounding civic infrastructure. Some elements in the student work remained untested and lacked the level of insight to allow students to understand their full impact.

As an example, the use of windfarms incorporated into the station structure, or the suggestions for Piezo-electricity generation would have very low impact on carbon reduction when compared to the opportunities facilitated via the PV solar systems on the large roofs. Students could have used parametric software to generate different design options to investigated a broader array of roof-shapes and the use of low-energy LED lighting to satisfy both interior and extensive exterior lighting requirements, but that opportunity seemed barely to have been tapped into.

6. SUMMARY OF CONSULTANT VETTING – Performance relative to BAU

The project feasibility study for the two selected projects found that the schemes developed by students resulted in credible solutions using market-ready technologies for the design of train stations.

Several initiatives assisted in the reduction of operational energy demand: Increasing heat-pump efficiency via smart temperature settings, changing from gas-fired to electric HVAC systems for heating and cooling, the replacement of conventional station lighting with low energy LED lighting, as well as an automated lighting control strategy linked to actual use via IoT technology. Via these initiatives, and assuming that only about 55% of the roof area covered enclosed spaces, the student feasibility vetting showed a 29% reduction (compared to Business as Usual – BAU) in operational energy demand could be achieved. For this high energy intensive train-station typology this a significant percentage.

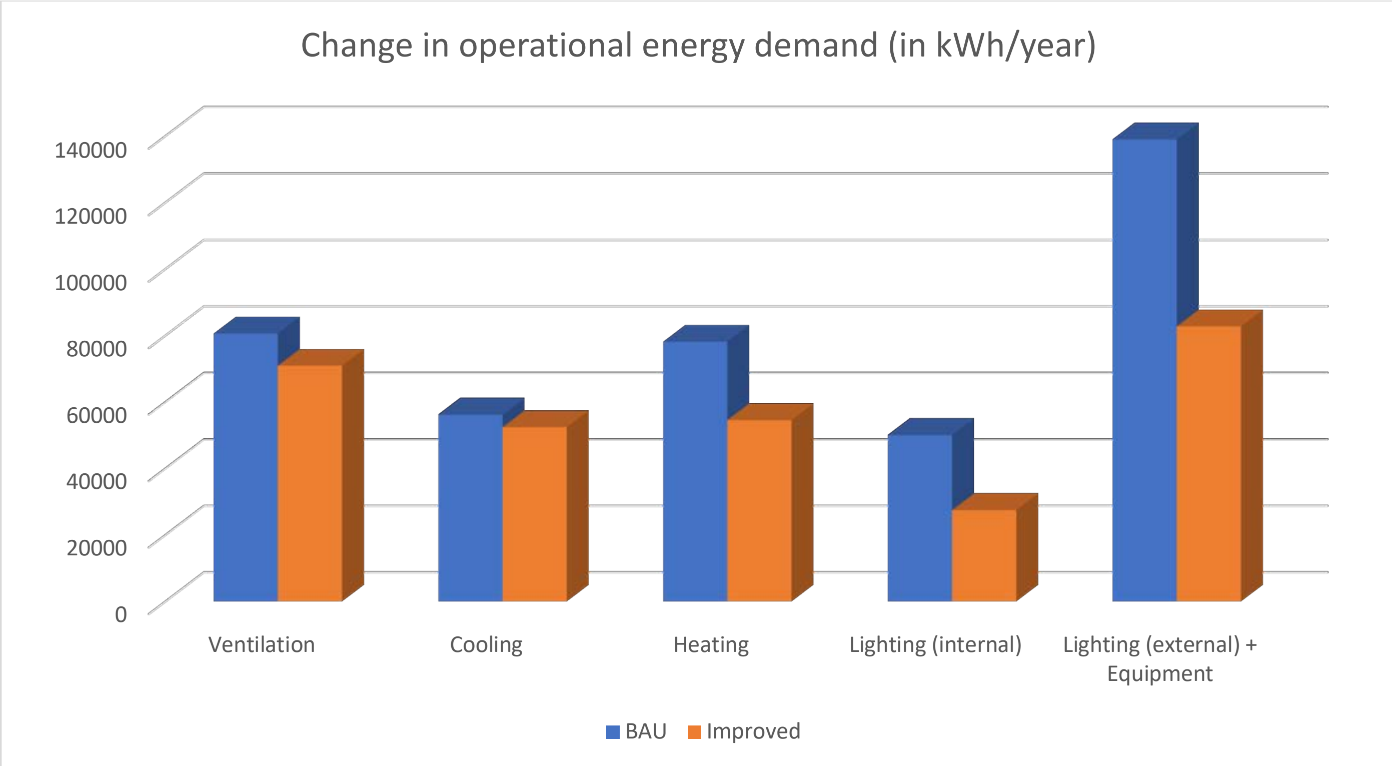


Figure 19: Project Vetting – Operational Energy Demand Reduction Strategies.

In addition to the above reduction in operational energy demand, other opportunities were investigated to provide additional onsite energy supply. Several options were investigated, such as wind farms, Piezo-electricity generation, and photovoltaic (PV) cells. Existing efforts around the world[1,2] highlight in particular the benefits of solar rooftop (or other) PV cells. For the student project vetting, the large roof areas of the stations with up to 2500m^2 of surface area did

[1] Folk, E (2022) Sustainable Innovations in Train Stations, BioEnergy Consult, https://www.bioenergyconsult.com/sustainable-innovations-in-train-stations/ last accessed 25 May 2022

[2] Chen et al (2022) Using existing infrastructures of high-speed railways for photovoltaic electricity generation, Resources, Conservation and Recycling, Vol 198, 106091, https://www.sciencedirect.com/science/article/pii/S0921344921006996?via%3Dihub, **last accessed 25 May 2022**

provide a major opportunity to investigate the use of photovoltaics in conjunction with battery usage. Analysis of the roof shape and orientation resulted in the proposition of four different solar array subsystems with panels tilted at 30 degrees of each orientation. Approximately 1200m2 of rooftop area could be covered by the PV cells, whilst still allowing natural daylight to penetrate the building via south-facing glazing in the roof. Combined, these subsystems have a capacity to provide **243,800 kWh/a** of energy supply, thereby offering approximately **60%** of energy supply when compared to BAU.

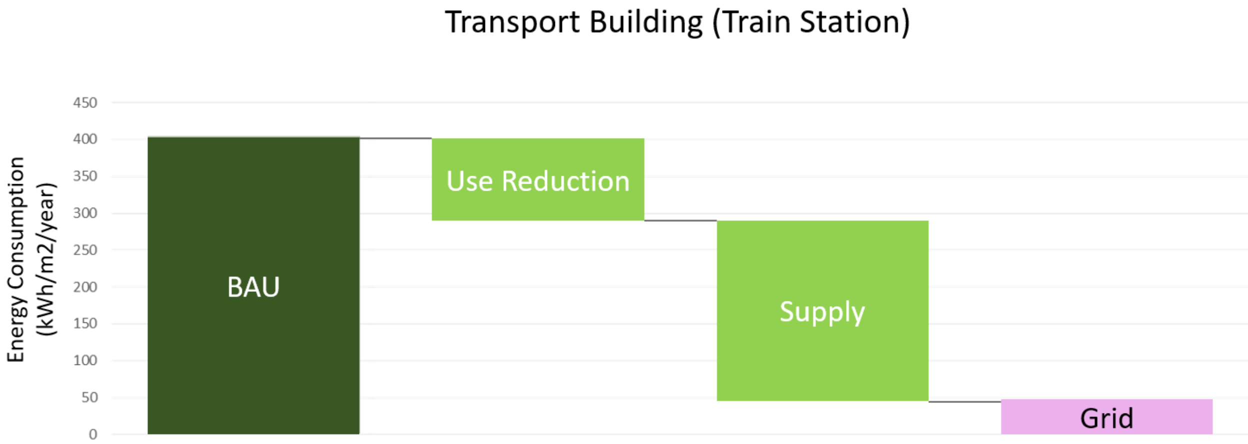


Figure 20: Project Vetting – Comparison: BAU, energy user reduction, supply and remaining supply from the grid.

Based on the analysis of the technologies investigated by students for their design of a train station, zero carbon solutions for this highly energy intensive building typology were not achieved, yet students found credible pathways towards significant energy reductions while implementing a holistic response to environmental, functional, and aesthetic concerns, achieving a total of approximately **89%** reduction in grid energy consumption when considering energy demand reduction (29%) and 60% on-site renewable supply of energy when compared to Business as Usual.

Figure 21: Group 2 Rail x Rail: Main Station Entry – Harlan Guo and Mason Mo

7. CONCLUSIONS

5.1 Conclusions and Next Steps

In this IDS, 4 team projects were delivered, exploring a wide variety of technologies and innovations to achieve community and sustainability goals for two exemplar train stations that form part of the LXRP. Approaches to each design are very different across the groups, but all proposals are trying to push the boundaries of conventional transport facility design whilst meeting the functional and operational needs of level-crossing removal and station upgrade that gives back to the community. Observations including the creation of an interdisciplinary language, shared goals, the success of an unconventional integrated process and the power of social connections have emerged. Each project is unique, yet some of the issues faced for design integration cut across all: integrating an intrinsic sustainability strategy, iterating based on valuable engineering insight and moving beyond individual egos.

Project participants advanced their designs for 14 weeks until mid-November and consultant feasibility vetting on 2 selected group projects occurred thereafter. There is a wealth of insight emergent from this studio, both in respect to integration in education and industry, and to net-zero and holistic sustainability outcomes in the AEC community. Net-zero targets seem close-to-be achievable with an 89% reduction in grid energy consumption when compared to BAU.

Figure 22: Group 2 Rail x Rail: Perspective Section – Harlan Guo and Mason Mo