The Innovation Hub

for Affordable Heating and Cooling

Lesson Learnt Report

IDS-06 Transport Buildings LXRP

Project IDS-06 v2.0

27th 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.

i-Hub Lessons Learnt Report

Guidance notes for completion of the Lessons Learnt Report:

- This report is intended to be made public.
- Please use plain English, minimise jargon or unnecessary technical terms.
- Please use your organisation's branding for the report.
- The report should meet your organisation's publishing standards.
- Please use one template per each major lesson learnt and include as many as are relevant for your sub-Project. If what you learnt is more technical, this is the section to include technical information.
- The content of these Lessons Learnt Reports can be compiled (and updated, where necessary) for inclusion in the (public) Project Knowledge Sharing Report, for submission at the completion of your sub-Project.

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

The integrated design studios are repeating format studios conducting research on two levels:

1) Integrated Design: Each studio builds upon previous studios to explore how best to facilitate integrated design between architects and engineers. Lessons are cumulative across studios.
2) Zero Carbon Research: Each studio explores zero carbon design measures that are relevant to the building typology featuring in that studio. Lessons are specific to the building typology used in the studio.

To improve readability (for readers reading multiple reports), material that has been repeated from previous reports as cumulative learnings has been delineated and identified as such. These lessons are shown on a greyed-out background.

New lessons learnt this IDS.

New lessons learnt this IDS.

Lesson learnt IDS-06 #1	Visual communication is the best universal language and is useful both for communication and as an analysis/collaborative thinking tool.					
Category	Technical – Integrated ‘Design					
Choose from:	*Technical*	*Commercial*	*Social*	*Regulatory*	*Logistical*	*Other (specify)*

Describe what you learnt about this aspect of the Project.

A valuable insight taken from IDS studios is that the power of visual communication is understood universally across disciplines.

An important moment of visual communication was the use of diagrams to explain logical design processes. For example the impact of structural layout on circulation or sightlines. This universal visual communication develops progressively over time, first, the team shared respect and understanding for the specialised knowledge and language. This was an early focus in the IDS through 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.

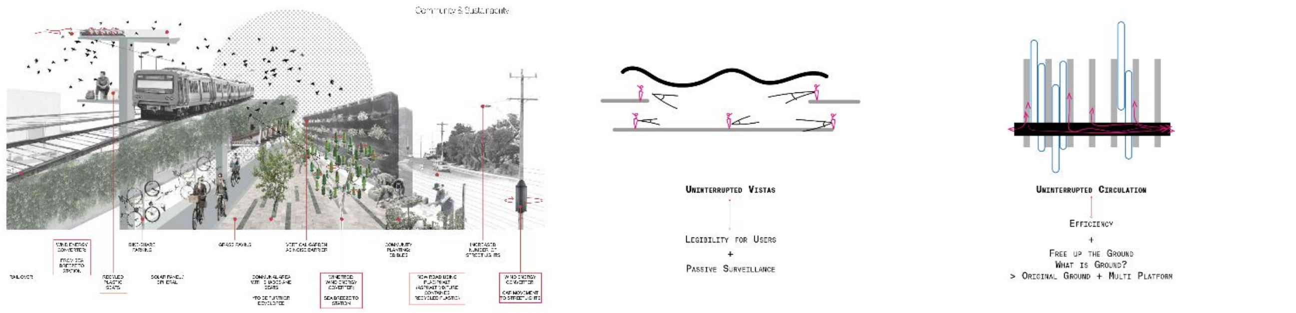


Figure: Examples of visual language, (a) annotated perspective with integrated technology, (b) diagrams of architectural and engineering design implications.

The process of drawing, presenting, and understanding became a form of problem interrogation (or analysis) that then facilitated integrated responses by allowing all disciplines to be involved in the critiquing and authoring of the refined solutions.

Please describe what you would do differently next time and how this would help. What are the implications for future Projects?

Encourage drawing as a presentation and workshopping tool earlier on in the integrated design process.

If your Project learnings have identified any knowledge gaps that need to be filled, please state it below.

None.

Please include any other information you feel is relevant or helpful in sharing the knowledge you learnt through this stage of the Project. This may be qualitative or quantitative and may include a graph, chart, infographic or table as appropriate.

Architects tend to be more comfortable with visual communication than engineers. This is likely due to each disciplines focus in design (architects on spatial aspects, engineers on performative aspects). I is also likely that his division is reinforced through education.

Lesson learnt IDS-06 #2	An informed process of interrogation and iteration can assist in the process of integration

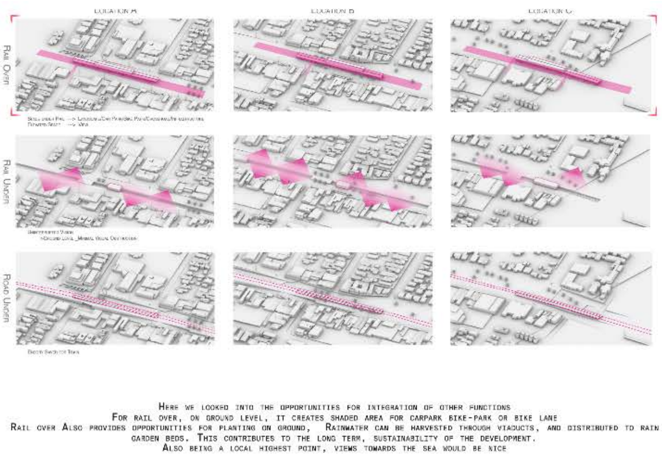
Category	Technical – Integrated ‘Design					
Choose from:	*Technical*	*Commercial*	*Social*	*Regulatory*	*Logistical*	*Other (specify)*

Describe what you learnt about this aspect of the Project.

An informed and intentional process can make a significant difference to the level of ‘integratedness’ of a project or team. In the conventional design process, the role of any engineering designer is to validate architectural design. It was 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:

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%



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

This concept was developed further when the criteria against which scenarios were being tested included architectural logic, achieving particularly engaging integrated results. The 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.

Please describe what you would do differently next time and how this would help. What are the implications for future Projects?

Encourage structured design charrettes using a intentional interrogate and iterate process with assessed oucomes at each stage.

If your Project learnings have identified any knowledge gaps that need to be filled, please state it below.

None.

Please include any other information you feel is relevant or helpful in sharing the knowledge you learnt through this stage of the Project. This may be qualitative or quantitative and may include a graph, chart, infographic or table as appropriate.

Assessment of outcomes needs to go beyond objective engineering parameters to place subjective values on architectural aspects such as aesthetics etc.

Lesson learnt IDS-06 #3	Time pressures on delivery often negatively impact integration.					
Category	Technical – Integrated ‘Design					
Choose from:	*Technical*	*Commercial*	*Social*	*Regulatory*	*Logistical*	*Other (specify)*

Describe what you learnt about this aspect of the Project.
A limiting feature of the integrated design process was observed to be the time for documentation 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.
Please describe what you would do differently next time and how this would help. What are the implications for future Projects?
Make designers aware of this articulating the need to establish integrated design strategies before the process ‘flips’ to one of documentation (when incorporating new ideas or developing the design is difficult).
If your Project learnings have identified any knowledge gaps that need to be filled, please state it below.
None.
Please include any other information you feel is relevant or helpful in sharing the knowledge you learnt through this stage of the Project. This may be qualitative or quantitative and may include a graph, chart, infographic or table as appropriate.
Nione.

Lesson learnt IDS-06 #4	An integrated design team is most effective in a comfortable space, encouraging innovation and experimentation, built on strong social connections.

Category	Technical – Integrated 'Design					
Choose from:	*Technical*	*Commercial*	*Social*	*Regulatory*	*Logistical*	*Other (specify)*

Describe what you learnt about this aspect of the Project.

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.

This is a known integrated design principle however this studio emphasised the importance of the social foundation aspect, something made possible by the face to face nature of delivery.

Please describe what you would do differently next time and how this would help. What are the implications for future Projects?

Pay particular heed to the social foundations of the studio creating a 'safe' environment for critique and feedback by arranging non-project encounters where designers can come to know each other.

If your Project learnings have identified any knowledge gaps that need to be filled, please state it below.

None.

Please include any other information you feel is relevant or helpful in sharing the knowledge you learnt through this stage of the Project. This may be qualitative or quantitative and may include a graph, chart, infographic or table as appropriate.

None.

Lesson learnt IDS-06 #5	Materiality is a nexus of integration, drawing together architecture, structure/ construction, and sustainability.					
Category	Technical – Integrated 'Design					
Choose from:	*Technical*	*Commercial*	*Social*	*Regulatory*	*Logistical*	*Other (specify)*

Describe what you learnt about this aspect of the Project.

This studio highlighted the importance of materiality as a nexus for design integration as it has direct and generally easily understandable impacts on all disciplines

An 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 demonstrated how material selection is an opportunity but also, if sustainability concerns are overlooked, a high-impact decision in terms of outcomes.

Please describe what you would do differently next time and how this would help. What are the implications for future Projects?

Bear in mind the opportunity to use material choice decisions as integrated design discussion initiators.

If your Project learnings have identified any knowledge gaps that need to be filled, please state it below.

None.

Please include any other information you feel is relevant or helpful in sharing the knowledge you learnt through this stage of the Project. This may be qualitative or quantitative and may include a graph, chart, infographic or table as appropriate.

None.

Lesson learnt IDS-06#6	Zero Carbon Design Measures Suitable for Stations.					
Category	Technical – Building Typology Zero Carbon Design					
Choose from:	*Technical*	*Commercial*	*Social*	*Regulatory*	*Logistical*	*Other (specify)*

Describe what you learnt about this aspect of the Project.

A select number of 2 group projects (Group 1 – 'Edithvale Exchange' and Group 4 'Uplifting Chelsea') were assessed further to verify feasibility of the initiatives proposed to achieve net zero carbon. 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 was 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.

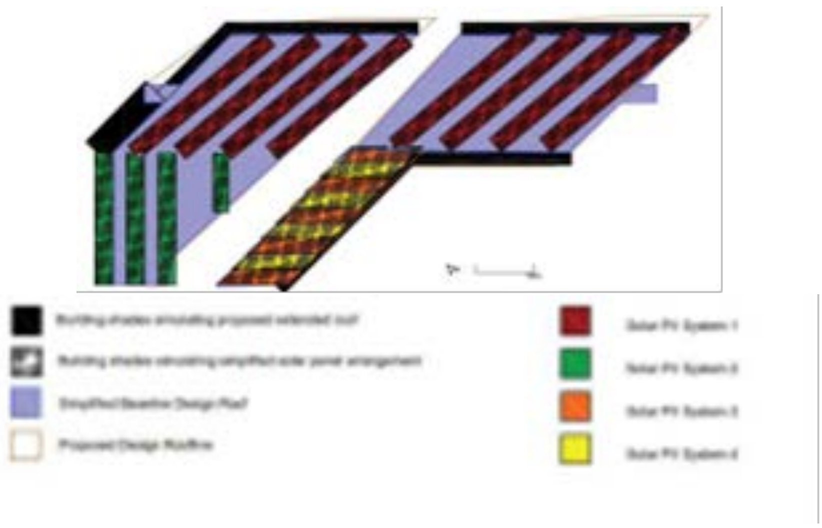


Figure: Simplified roof layout for eQuest simulation

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.

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

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 source heat pumps, wind farming, and Piezo-electricity generation.

Key initiatives can be summarised as follows:

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

The feasibility vetting of designs produced for two case study stations (Chelsea and Edithvale), found that the schemes developed by students resulted in credible solutions using market-ready technologies for the design 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 internet of things (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.

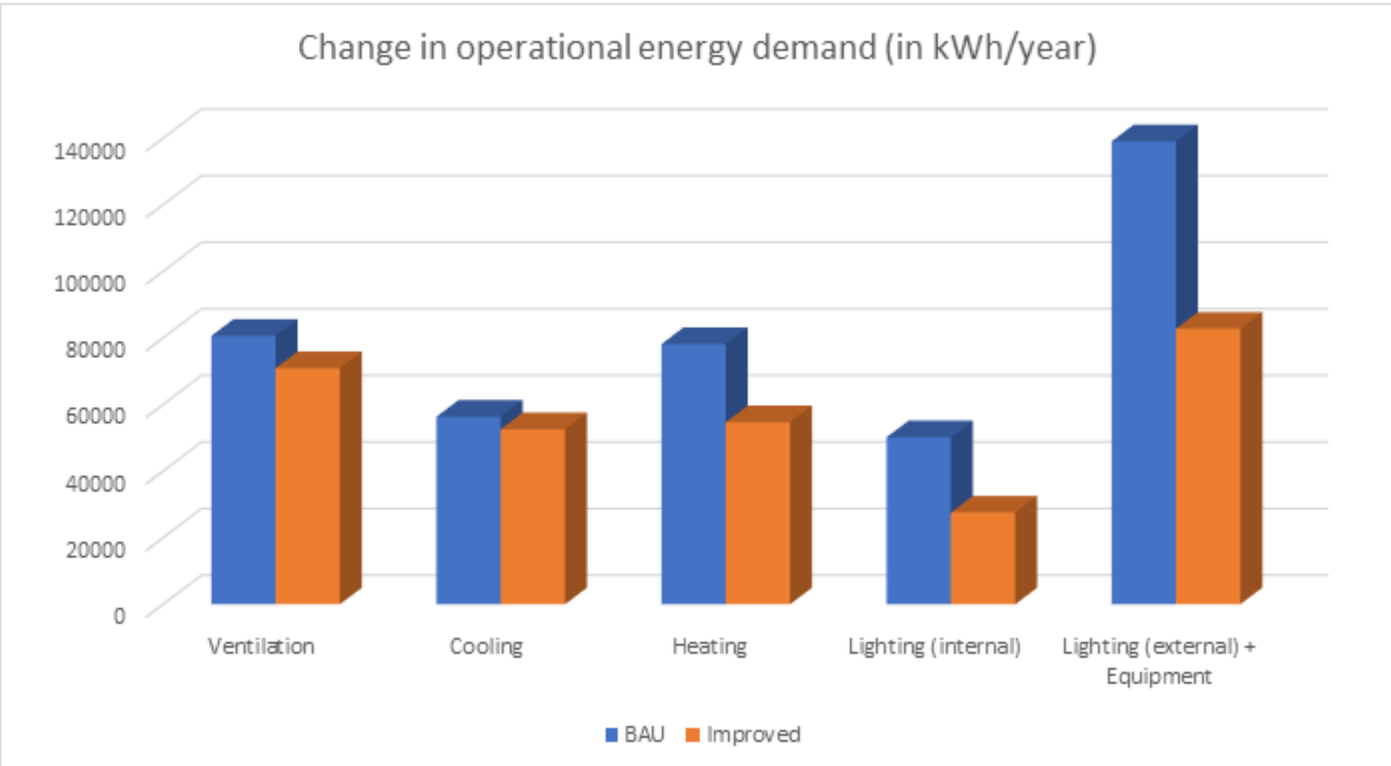
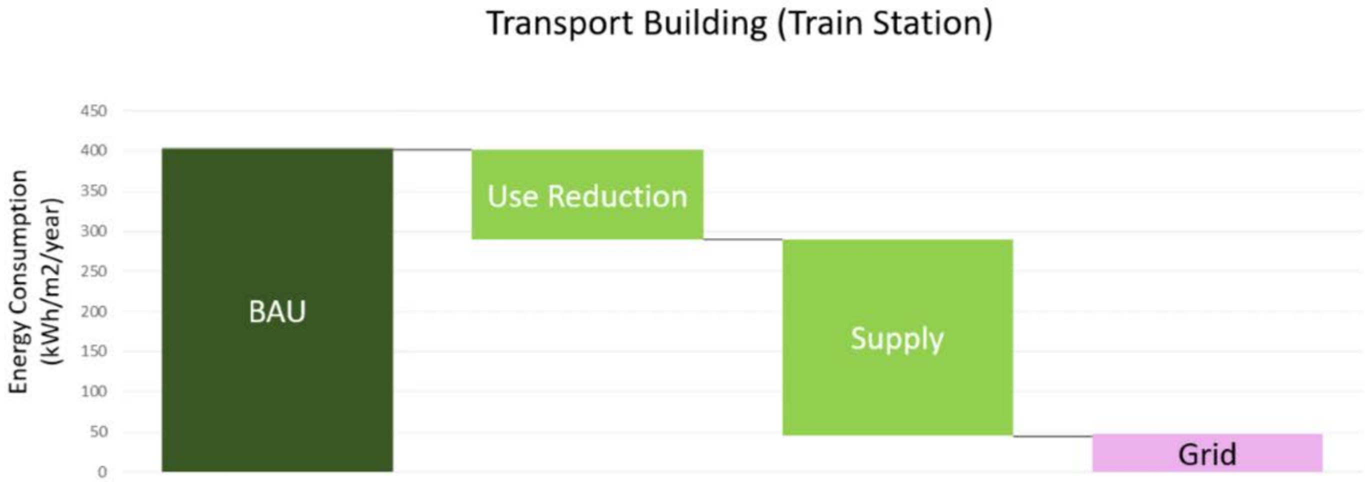


Figure 19: Project Vetting – Operational Energy Demand Reduction Strategies

In addition to the above reduction in operational energy demand, other opportunities were investigated to provide additional onsite generation. 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 2500m2 of surface area did 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.



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.

Please describe what you would do differently next time and how this would help. What are the implications for future Projects?

The buildings component of the stations designs tended to dominate the focus of sustainability measures. In future iterations focus direction would be directed to the platforms and rail components earlier and more precedent studies would be tabled on sustainability work already undertaken by PTV and existing consultants.

If your Project learnings have identified any knowledge gaps that need to be filled, please state it below.

The project highlighted materials as an essential consideration in reducing carbon. Emerging concerns around the mercury (Hg) levels in fly ash used to replace cement present a potential threat to its continued use. The whole sustainability industry would benefit from further research in this area. As a large educated client often instigating project and network wide specifications organisations like PTV and LXRP are in a good position to assist in undertaking work on this front.

Please include any other information you feel is relevant or helpful in sharing the knowledge you learnt through this stage of the Project. This may be qualitative or quantitative and may include a graph, chart, infographic or table as appropriate.

None – refer to 100% Studio report containing consultant feasibility vetting report for more detail on the above summarised learnings.

Lessons on Integrated Design learnt from previous IDSs.

The lessons reproduced below present the cumulative learnings built across subsequent studios. They relate to generalist learnings on 'Integrated Design' and are applicable to all studios.

For 'Zero Carbon Design' learnings specific to the building typologies chosen as case studies for the studios, refer to the lessons learnt report for each specific studio.

Summary of relevant lessons learnt from previous IDSs.

(Refer to the 'Lessons Learnt' reports for studio referenced for more detail).

Category	Technical – Integrated Design

IDS-01 #1	Good integrated design requires a 'design co-author' mindset in all participant designers.

Current design paradigms often place engineering as following architecture in the design process. This encourages a consulting type approach to the engineering where engineers are asked to comment on preformed ideas. Design integration can occur in this model however to a reduced potential with the initial ideation missing ideas founded in engineering aspects of the project. The studios found this consulting model to be difficult to break free from. Attention needs to be paid to create a mindset of 'design co-authorship' in all participants (engineers and architects alike). The reasons for this are not immediately clear however we believe may be related to:

- Potential deficiencies in creative thinking education in degree content.
- Established practices in industry (i.e. accepted established role as consultants).
- Early career stage (more experienced engineers were found to be better at ideation that younger engineers).
- Disparity in time available to be dedicated to studio ideation.

Lessons to be incorporated into future studios:

- Emphasise the concept of co-authorship in ideation more heavily.
- Aim for a better balance in numbers between architects and engineers.
- Aim for a better balance of seniority between architects and engineers (to encourage approachability and reduce fear of failure in putting ideas forward).
- Introduce common tasks at a detailed analysis level as well as the high aspirations level to encourage interaction between architects and engineers with common goals. This is anticipated to foster more detailed generation of ideas between the two disciplines.

IDS-01 #2	Integrated design ideation happens in a limited time window after designers reach a level of base understanding of the disciplines to be integrated.

In a 13-15 week design programme much of the front end is taken up with briefing and bringing design parties up to speed with each other's discipline (in general knowledge terms), the back end is conversely dominated by design development and documentation type activities. In-between these two general phases is a brief period when core design ideas are generated and formed. Once design ideas are formed it is difficult to materially change direction due to the momentum involved. Designers hold preconceptions after this initial ideation and the natural tendency is to adjust direction rather than to discard totally to start again. It is important to recognised when this ideation period is happening ensuring everything and everyone is in place to make it as successful as it can be.

Lessons to be incorporated into future studios:

In future studios more attention will be placed on this important ideation time. We may even give it a name so that the participants are aware of it and treat it with the degree of importance and priority it requires.

Additional Learnings from IDS-03 #2 & #5

Base level of understanding required in disciplines to be integrated before integration can happen effectively. Student designers solutions at mid semester were found to be pedestrian reflecting upskilling to understand what BAU is in each discipline. It was after this point that design integration and innovation was able to be productively pushed. This reflects research on polymath creativity across knowledge domains by Kaufman et al., 2010, Creativity polymathy: What Benjamin Franklin can teach your kindergartener. Likely for the same reason more experienced designers are quicker to commence, and more effective at integrated design ideation.

IDS-01 #3	Balance between architecture and engineering requires active curation.

IDS-01 took the approach of asking designers to approach the design from the two disciplinary extremes (architecture and engineering), from the beginning producing designs they felt represented each (ignoring the other). This approach emphasised the differences in the two approaches in designer's minds and articulated the prospects of needing to navigate the spectrum in-between the extremes in future design. Once equipped with this perspective it was easier for designers to understand that it is a balance between the two. Observations in the other IDS observed found that designers tended to follow the information in front of them without necessarily understanding the extents of the design spectrum.

This learning is a subset of the larger learning that active curation of the process is beneficial. There were conflicting opinions coming out of the interviews as to where this curation should sit. Some believed this should be the job of the architect, others believed a third party.

Additional Learnings from IDS-03 #3
The importance of the design curation was found to be even more important than first thought in IDS-03 to IDS-05 as relayed by stakeholders interviewed (Refer Lesson IDS-03 #03). Further investigation is required to establish if this is heightened due to the studio leader's joint role as 'teacher' in the studios. Differing opinions on where this design curation role best sits were also evident. Some believed this role should in the architect's remit, others believe it should be a third party independent to the architect and engineer.

Lessons to be incorporated into future studios:
In future studios we will consider adjusting the integrated design process to encourage this exploration of the extremes between the two disciplines views of the project and also discuss where this curation role bests sits.

IDS-01 #4	There is a high level of excitement and buy in to the concept of integrated design.

A high level of excitement and buy in to the concept of integration was observed in all involved (demonstrated by studio popularity with students and keenness to be involved by participants). It is clear that the benefits are recognised. This may suggest that existing failures to follow a design integration path in industry occur as it is simply not an up-front agenda item.

Lessons to be incorporated into future studios:
Further work identifying the gap between practitioners and clients buy in, and the failure to see integrated design realised more in industry is worthy of further research.

IDS-KS #1	Integrated Design Process - one size does not fit all

In taking the integrated design process consolidated from the literature search and applying it to the first two integrated design studios (IDS's) in practice, it was clear that the process needed a high degree of customisation. Variations between the studios included tailoring for:

- Studio Leaders style/preferences. While the studio leader is an IDS specific role and will not exist per se in practice, the individual styles and preferences of the players involved in leading design will. We felt it important to let the leaders dictate aspects related to their style of working to get buy in and maximise chances of success. We expect this will be an element that needs to be considered in implementing successful integrated design teams and environments in practice.
- Technical content. The high level of technical content involved in data centre design and achieving efficiency meant that addit. measures had to be taken to ensure architecture received adequate air time.
- Willingness and available time to be involved. All parties were keen however subject to various constraints. It was important to consider this in the input (frequency and duration).
- Ability to see the forest for the trees. The presence of a third party design leader or curator was important in providing perspective to the designers, someone outside and removed from the design who could provide feedback if the design was straying too far towards one discipline or the other.

IDS-KS #2	Establishing Integrated Design extremes (or discipline goal posts) helps.

One of the preliminary observations in relation to process was that the curation of balance between architecture and engineering looks like it will be more successful when there is an element of inherent way finding. One of the studios asked designers to produce two designs, one from an architect's view ignoring engineering, and vice versa.

This appears to have offered some benefits in assisting the designers to set the goal posts – i.e. what might pure architecture look like, and what might pure engineering look like and how do we balance and achieve the best outcomes from there. Designers who did not do this tended to be taken along a narrower path following their noses in design development rather than knowing the possible bounds.

IDS-03 #1	Precedent disparities exist in the working frameworks architects and engineers bring to projects.

Disparities exist in the frameworks architects and engineers work within when involved in design.

Lessons to be incorporated into future studios:

- Introducing smaller task specific activities with common goals helped in bringing individuals (architects and engineers), together. An example of this were tasks set to work with a common software tool to analyse performance of a small manageable part of the building.
- More closely aligned definable goals. Efforts were made to establish common goals in design however these were usually general in nature, i.e. zero net energy, better sustainability, more renewable energy etc. Design under these 'loose' aspirational goals often strayed whereas design in more defined tasks such as teams researching specific solutions (say labyrinth's or heat pumps etc), provided better focus. A part of this will be pre-semester efforts to try and more closely align assessment criteria between disciplines.
- Straight out reductions in disparities establishing as level a playing field as possible. Efforts will also be made in this front, i.e. achieving similar time allocations between students through the formation or adjustment of subjects between the faculties.

IDS-03 #2	Experience levels of designers is an important consideration in integrated design.

Experience levels were found to impact on integrated design capability. Student (and early career consultants) were found to be capable in analysis but not necessarily design. This learning came from observing the nature of design development. Designs were found to be 'pedestrian' or Business as usual' (BAU) in nature up until the mid-semester critiques. We feel this is because the first half of semester is the time students required to become 'familiar' or 'comfortable' with the problem definition and the new cross discipline skills/appreciation they are acquiring. It is only after this point that designers felt more at ease experimenting and pushing boundaries. The more experienced consultants in the design team were observed to be much better at integrated design in this respect (although not exclusively).

The learning from this is an increase in the initial familiarisation time required before the 'sweet spot' of design integration is able to productively occur.

Lessons to be incorporated into future studios:

Educate designers about the process of developing an understanding of the fundamentals before experimentation and productive design integration can effectively occur. Note that this does not mean that thinking about potential creative ideation and design integration should be ignored or not happen early on, just that it is unlikely to be productive until a sound understanding of the fundamentals is gained.

IDS-03 #4	Architects and engineers have different preferences in communicating and engaging.

Difference in personalities and preferred methods of communicating and engaging is becoming evident. Students from the two faculties engage differently on a number of fronts:

- Engineering students prefer more defined problems and better defined problem solving frameworks in which to work on them than architects.
- Engineers tend to be less communicative in open studio forums (more likely to have video switched off etc.).
- Engineers tend to be more comfortable with analytical tasks involving and metrics and specific outcomes.

It was felt that these differences hindered collaborations. The differences reduced over time in the studios. Further investigation as to the reasons underlying the differences and potential amelioration is required including exploring the benefits of introducing socialising activities external to the design process. It was noted that engineers in one studio (IDS-04), were highly engaged and this may have been due to the presence of one or two individuals with 'more collaborative and energetic attitude' acting to encourage others.

IDS-03 #5	Base level of understanding required in disciplines to be integrated before integration can happen effectively.

A base level of understanding was found to be required in the disciplines to be integrated before integration can happen effectively. Student designer's solutions at mid semester were found to be pedestrian (average) in quality reflecting student's upskilling to understand what business as usual (BAU) is in each discipline. It was only after this point in the studio that design integration and innovation was able to be productively pushed.

This reflects research on polymath creativity across knowledge domains by Kaufman et al., 2010, Creativity polymathy: What Benjamin Franklin can teach your kindergartener. Likely for the same reason more experienced designers are quicker to commence, and more effective at integrated design ideation.

IDS-07 #1	Face-Face interaction is an important factor in facilitating integrated design.

A notable increase in the engagement and interaction between student designers (particularly engineers), was observed in IDS-07. This is thought to be attributable primarily to the face-face mode of delivery. 'In studio' interactions were far stronger due to communication mode and sense of commitment in a physical environment. The number and nature of conversations increased (i.e. formal and informal).

Anecdotal evidence from consultants on projects requiring remote delivery (i.e. international design teams or teams removed from project location) supported this. The practice of ensuring initial face to face interactions with a degree of social interaction between project members prior to them continuing to work together remotely on a project was noted as a method of strengthening communication and collaboration.

A secondary influencing factor was the changed nature of recruitment in IDS-07 for the engineers. Greater detail was provided on the purpose of the studios. This it was felt resulted in a degree of self-selection as students with particular interests in sustainability and integrated design were attracted.
Quote from RA observations: "Face-to-face contact of students allowed for social bonding and the establishment of a proper 'group mentality' among architecture and engineering students".

Lesson learnt IDS-07 #2	Easily accessible software tools for interrogating technical performance is important to early design/integration process.
IDS-07 demonstrated the importance of designers having access to decision making tools in the form of software that enabled them to assess outcome. This both provided a common language that designers could use to interact and enabled quantifiable prioritisation of various solutions (options). RA direct observation: “Students were found to be most likely to engage with and understand the impact of environmentally focused design decisions through the process of iteration. With the introduction of the Ladybug Tools platform to the students, tangible environmental impacts were able to be discovered within the student’s design tool of choice. Significant uplift in comparison with previous semesters regarding the student’s excitement and engagement were found as they developed their skills within this parametric software, which is easily translated into other aspects of their design skills. Further development of the base tools and strategies involved with the introduction of these tools are recommended for further studios, as it’s relevance to the students’ growth is recognised both within the studio and beyond. …These activities allowed designers to better understand the relationship between good design and performance and inform their understanding of how buildings work together”. Atelier 10 (sustainability consultant) direct observation: “hands-on experience of testing the performance of their designs gave students a heightened awareness of the full impact of their design decisions”	