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FOSTERING INTEGRATED DESIGN IN AN ACADEMIC ENVIRONMENT: PROCESS AND A METHOD

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Abstract. In conventional building design projects architects make pre-design and conceptual design decisions on buildings and hand these down to structural and building services engineers to follow up with design development. It is well known that the conceptual design stage of a project is the point where decisions make the most impact, and changes can be made at least cost. The sustainability and innovation aspects of projects often suffer in this respect. One way of addressing this is through Integrated Design Methods that set out mobilise the full potential of all design disciplines on a project by getting them to work effectively together. This method involves architect, engineers, contractors, and owners/clients in all design phases. The current literature reported fundamental principles and processes of Integrated Design however current industry practices do not fully embrace them. Introducing integrated design studios into university pedagogies is a key step in addressing this. Reports on methods of setting up integrated design studios in a university context are however rare. The aim of this article is to develop and document the underlying settings for such design studios. The principles and best practices for applying integrated design are identified. A specific framework of settings in university context is developed and the justifications presented. This article may be of value for the industry and universities to setup integrated design studios to better foster integrated design education.

Keywords: integrated design process, building design, design studio, sustainability, best practice.

Introduction

Most buildings that perform poorly do so as a result of the subdivision of responsibility and accountability by time and by professional discipline (Rush, 1991). Most current design processes and design tools seem to be intended for individual designers with no attention for explicit teamwork embedded within them (Valkenburg, 1998). This is one of many significant cultural barriers to innovation for creating high performance buildings at the component level (where individual products are selected and combined to create the final design). Other reasons include the increasing segregation of the construction industry into more specialized consultants (Rush, 1991), lack of consultant fees/lack of value placed on the consultant's ability to innovate, poor communication, lack of competition, and different modes of thinking (convergent using logic, divergent using imagination, and lateral using both logic and imagination) between disciplines. The result is an inability to bring the engineering and architectural disciplines together to effectively co-design high performance buildings.

It is well known that the conceptual design stage of a project is the point where decisions make the most impact, and changes can be made at least cost. The sustainability aspects of projects often suffer in this respect. For example, missed opportunities for renewable energy are typically locked in at the early stages of the design before Heating Ventilation and Air Conditioning (HVAC) engineers become involved. To address this cultural barrier and facilitate incorporation of these measures into design Integrative Design Process's (IDP's) have been developed and can be applied in project delivery (7group & Reed, 2009). IDP's enable co-creation of new ideas better integrating building components (e.g. building envelop, HVAC systems, energy generation, and energy storage) into architectural design. As a part of the process concept design reports and associated communications collateral convey the benefits of the resulting integrated design concepts and the indicative performance gained forming the

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initial output of the process. These enable asset owners to identify "ideas of interest" that would then be further developed to prove feasibility. Once proven against industry benchmarks, ideas are able to be adopted in projects (current or future), and ultimately make their way into wider industry adoption.

The available literature (Steemers, 2006; 7group & Reed 2009; Lovins, 2010; Blizzard & Klotz, 2012; Casakin & Ginsburg, 2018) reported fundamental principles and processes of Integrated Design. Current industry practices do not fully embrace these integrated design principles and processes. An underlying reason for this is that architecture and engineering students are typically taught design separately. Blizzard et al. (2012) evaluated the effectiveness of introducing whole-systems design (the basis integrated design), with case studies in multiple sections of a first-year engineering course. They reported that the case studies improve students' consideration of several essential whole-systems design concepts. Van den Beemt et al. (2020) reported that interdisciplinarity in higher education is often implemented by mono-disciplinary people (Blizzard et al., 2012). To fully embed these integrated design principles in architecture and engineering degrees, integrated design studios, where students from both disciplines learn and develop the skills together are required. Such studios offer valuable practical learning opportunities in collaboration and real life application of design as they will likely represent the closest experience students will have to real design environments prior to graduating. Reports on method of setting up integrated design studios are however rare in the university context. The aim of this article is to develop and document settings for such studios. To achieve the aim firstly the principles and best practices for applying integrated design are identified via a literature review. Secondly, our reflections on the approach and challenges in a university context are presented and discussed. The main elements to be considered in establishing university integrated design studios are then developed and presented based on the literature forming our contribution to knowledge. The justifications of the setup and challenges experienced in practical implementation (by the authors), are also presented. This article may be of value for industry and universities to inform the setup of integrated design studios to better foster integrated design education.

1. Integrated design principles

Whole-system thinking forms the basis for "integrated design" in that it optimizes entire systems as a whole, rather than component parts in isolation. In literature integrated design is also coined as "whole systems design", a collaborative design-based approach intended to promote collective theories and disciplines (Pittman, 2004). Based on Rocky Mountain Institute's discussion (Lovins et al., 2010, p. 7) Blizzard and Klotz (2012) adapted a definition for "whole systems design" for generalised applicability across design disciplines as follows:

> "Whole systems design considers an entire system as a whole from multiple perspectives to understand how its parts can work together as a system to create synergies and solve multiple design problems simultaneously. It is an *interdisciplinary*, *collaborative*, and *iterative* process."

Blizzard and Klotz (2012) systematically reviewed 49 articles (published between 1981 and 2010) and developed a universal framework outlining the process, principles, and methods of whole systems design. Table 1 shows the resulting framework.

Lovins et al. (2010) at Rocky Mountain Institute (RMI) identified 17 principles for applying integrated approach to practical design (Table 2). This list was selected as particularly useful because of its comprehensiveness across the design process.

Ten design principles applied in integrated design specifically for energy efficiency were presented by Lovins (2010):

1. Focusing on the desired end-use places purposes and application before equipment, efficiency before supply, passive before active, simple before complex.
2. Broadening design scope embraces whole systems and sets end-use performance metrics.
3. Designing from scratch, at least initially, creatively harnesses "beginner's mind", spans disciplinary silos, surpasses traditional solutions, and further expands the design space.
4. Analysing gaps between theoretical minimum requirements and typical usage reveals overlooked opportunities for elegant frugality.

Table 1. Whole systems design framework (adapted from Blizzard and Klotz, 2012)

Process	Establish a common vision – then align goals and incentive	Practice mutual learning		Share all information with everyone	
Principles	Maintain focus on the fundamental desired outcome	Learn from nature		Apply systems thinking	
Methods	Define scope to align with vision and desired outcomes Design on a clean sheet Start design analysis at the end-use and work upstream	Seek simple, elegant solutions Value place Move resource impact towards zero	Rethink waste Use renewable inputs Use non-hazardous materials	Seek multiple benefits from single expenditure Protect and restore natural, social, and economic systems Build in feedback	Consider the entire life-cycle of the system Tunnel through the cost barrier

5. Optimizing systems, not isolated parts, lets single expenditures yield multiple benefits.
6. Evidence-based analysis supplants rules of thumb.
7. Measurement and prudence replace mindless oversizing and allow operational risks to be managed explicitly and intelligently.
8. End-use savings multiply upstream energy and capital savings, so efficiency logic is sequenced in the direction opposite to energy flow.
9. Design satisfies rare conditions (making appropriate trade-offs and engaging end-users) but emphasizes typical conditions to maximize performance integrated over the range.
10. Controls and embedded sensors create intelligence and learning, so design can be optimized in real operation and further improved in future applications.

ANSI Standard Guide describes the integrative process which includes iterative process of research/analysis and workshop (Table 3).

Table 2. Integrative design stages and process principles (adapted from Lovins et al., 2010)

Stage	Process principle
Create an Integrative Design Process	Define shared and aggressive goals
	Collaborate across disciplines
	Design nonlinearly (iterative and recursive)
	Reward desired outcomes
Focus on the Right Design Problem	Define the end-use
	Seek systemic causes and ultimate purposes
	Optimise over time and space
	Establish baseline parametric values
	Establish the minimum energy or resource theoretically required, then identify and minimise constraints to achieving that minimum in practice
Design Integratively	Start with a clean sheet
	Use measured data and explicit analysis, not assumptions and rules
	Start downstream
	Seek radical simplicity
	Tunnel through the cost barrier
	Wring multiple benefits from single expenditures
	Meet minimised peak demand; optimise over integrated demand
	Include feedback in the design

Table 3. ANSI Standard Guide (source: American National Standards Institute, 2012)

A1	Research/analysis – Individual expert team members initially develop a rough understanding of the issues associated with the project before meeting – these issues are associated with ecological systems, energy systems, water systems, material resources, skill resources. This occurs so the design process can begin with a common understanding of the base issues
W1	Workshop – The team members come together with all stakeholders in the first workshop (charrette) to compare ideas, to set performance goals, and to begin forming a cohesive team that functions as a consortium of co-designers. By being in relationship to each other, each team member invites the issues associated with the system for which he or she is responsible to come into relationship with all others, so that a more integrated and optimized project results
A2	Research/analysis – Team members go back to work on their respective issues – refining the analysis, testing alternatives, comparing notes, and generating ideas in smaller meetings
W2	Workshop – The team reassembles for a deep discussion of overlapping benefits and opportunities – how best to utilize the "waste" products from one system to benefit other systems. New opportunities are discovered, explored and tested across disciplines, new questions are raised, and cost issues are evaluated
A3	Research/analysis – Team members go apart again to design and analyse with more focus and potentially with greater benefits accruing. New ideas are uncovered
W3	Workshop (s) – The team reassembles once again to further refine the design and to optimize systems being used (building and mechanical systems) and to integrate systems connected with the project (energy, water, habitat, materials, etc.). Cost issues are further analysed and optimised
An	…
Wn	…
This pattern continues until iterative solutions move as far as the team and client wish. Simply stated, good integration is a continuously dynamic iterative process	

These principles formed the initial basis of a program of integrated design studios (IDS) set up within an academic (university) environment, to study how integrated design works in practice. A reflective account on how this IDS program was set up in terms of stakeholder engagement, funding-body agreements, and industry outreach are presented in the next section.

2. Setting up the IDS program: government/ industry/academia

In the following subsections detailed descriptions of how the Integrated Design Studio program was formed and how it was set up as part of a wider research program involving government, industry and different academic institutions are provided. The approach and the initial challenges experienced are also discussed.

2.1. Project initiation (collaboration across architecture and engineering faculties)

The research presented here originates from a joint effort between the Architecture and the Engineering faculties of the authors' home institution. At the outset, members of the two faculties identified a gap in current design practice, where project participants often only view their own specific discipline's part of deliverables, whilst lacking empathy (or sometimes even ability) to examine design problems more holistically in an integrated way. Their goal was therefore to understand the reasons for this schism and to investigate pathways to introduce stronger emphasis and better facilitation of integrated design principles. The academic design studio setting (common in architectural design schools) was identified as the key mechanism to setup an environment where integrated design could unfold. Engineering students were introduced to the traditional architecture student design studios to enable joint work on complex design problems. Environmentally sustainable (and in particular Zero Carbon) design, was selected as the central topic for the two faculties around which to organise the program, this was believed to be appropriate given the large number of disciplines contributing to sustainability and it's propensity to systems thinking. In order to facilitate research in this field, funding was sought to allow a focused two-to-three year observational study of the how integrated design happens between architects and engineers in project design environments.

2.2. Involving industry bodies and government agencies

The research presented in this paper was enabled via an extensive effort to connect stakeholders from within government, industry and academia, and to align their interests surrounding environmentally sustainable (and in particular Zero Carbon) design. In order for this to occur, members of the authoring team joined forces with a national industry body representing stakeholders from the HVAC industry (The Australian Institute of Refrigeration, Air conditioning and Heating (AIRAH)) and a number of other academic institutions, to apply for a government grant issued by the local environmental sustainability agency as part of their "Advancing Renewables" Program. Under the main umbrella, three interlinked activity streams address new technologies that support Zero Carbon initiatives in the built environment of which the integrated design studios was one:

Program 1 to establish real-world test beds for technologies to be tested and validated in as-constructed environments,

Program 2 to create the data platform upon which data-driven technologies can be based that enable the HVAC/on-site renewable generation optimisation to occur, and

Program 3 *[Integrated Design Studios (IDS)]* to research how integrated design processes work in practice to drive the application of value-enhanced renewable energy technologies into actual building projects.

A two-year project grant by the government agency, and administered by the main contract partner (AIRAH) as the conduit for all activities was awarded in December 2019. It should be noted that the duration from the time of conceptualization (July 2017) to the time of grant awarded was about two and half years. Upon the award the authors developed a structure for the Integrated Design Studios to be run at their home institution and after a period of time (one year), extended to other partner institutions.

2.3. Structure/approach

The Integrated Design Studio (IDS) program was set up with the primary objective of studying how architects and engineers interact in an integrative design environment in practice. By using case study projects a secondary outcome was able to be achieved of exploring sustainable design outcomes that cut across architectural and engineering domains arising from the integrated design method. The Integrated Design Studios (IDS's) are "design research" environments hosted by universities building from traditional design studios (typically held in architectural degrees). They are different in that they add: Clients with real projects, Consulting architects and engineers from industry, and Academics from the university. The Studios have been set up as win-win-win project incubators (Figure 1) with each participant bringing something to the studio to benefit the process but also taking away an experience of benefit. Each IDS has a new project/client as the basis for the studio. Clients bring project brief and client feedback into design. This is important as it may relate to aspects not always considered by architects and engineers, for example, business related constraints like what can be insured or operations-based policies achieving business efficiencies etc. Clients win through access to early ideas about what their new building could be. Students form the core of the design labour available; pro's include energy, interest, and absence of preconceptions which can hinder innovation. Con's include lack of experience and a developing level of subject knowledge. Having a class of students has the advantage of being able to research and develop multiple potential solutions and approaches at the same time. Students win by getting to work on real projects alongside real industry people. Consultants bring a deep knowledge of subject matter, real world design experience (including design stories – for inspiration and to convey real world learning), and advanced communication and negotiation skills. Consultants win with access to like-minded clients to develop new design ideas and possible new business as well as getting introductions to students for possible recruitment. Academics bring depth of subject knowledge and teaching/research expertise and win along with the Universities through more research and better engagement with industry.

This process required a number of steps that divert from the typical setup of academic Design Studio' courses. Firstly, the authors needed to promote the IDS program to potential clients in order to gain their interest in participating with "actual projects", secondly, industry consultants for each IDS needed to be found, who were willing to dedicate their time to the studio at a reduced fee (that did not fully cover their costs). The authors then liaised with the program director of the existing design studio program to seek alignment with the IDS desired research output whist still maintaining the academic outcomes required in the Master-level program. All of the above was undertaken in parallel with an ethics application to address any potential risks or other potentially adverse consequences of overlaying an existing design studio program with a targeted research component that involves industry, as well as requiring students from different Faculties to work on a joint project.

IDS's are conducted in the mostly "risk-free" environment of tertiary education, IDSs run each semester are used to test the opportunities for architects and engineers to work collaboratively on common goals whilst closely observing the key moments/instances that lead to integrated design outcomes. In order for this to work, the project's initiators spent nearly two years liaising with key parties to fine-tune the development of the IDS structure in its current form. It foresees the involvement of design students from architecture and engineering background, who jointly develop ideas and design concepts using a process reflective of the integrated principles identified in Section 1, with input from industry professionals and academic experts. This process, which runs under the umbrella of an existing school of design Masters-level studio program (with adjunct engineering subjects), gets closely monitored by researchers from both the school of architecture and the school of engineering. For each IDS, a brief is developed with client who also provides essential references for the hypothetical project to be developed by the students, as well as the desired deliverable at the end of semester. The hypothetical project is formulated to be as real as possible with an actual site chosen which presents real design constraints to which to respond. An experienced studio tutor guides the students through the 13 week semester. Architecture and Engineering students are encouraged to design and present jointly. As in industry however, there are unavoidable differences, in the case of the studios it is a number of different education outcomes (competencies), required to be delivered by the course accrediting bodies. This means the different students are supervised and assessed by the respective schools. The overarching design process is however delivered as integratively as possible. While integrated design is applicable to all technical disciplines a focus environmental sustainability (goals) was encouraged. This is due to the inherent multidisciplinary nature of sustainability as well as the underlying funding remit of improving energy performance. The intent of the program is to examine how architects and engineers put their heads together when aiming for transformative solutions that go beyond simply adding the input of each discrete discipline.

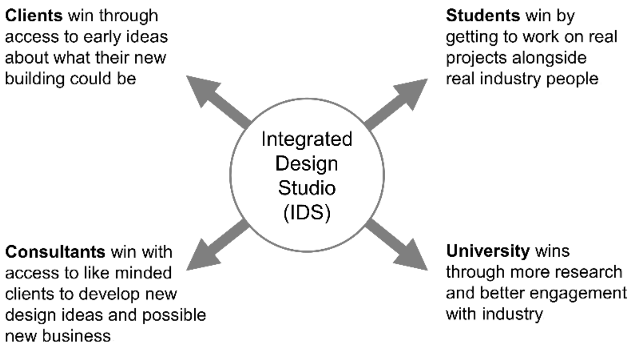

Figure 1. Benefits of Integrated Design Studio to the participants

2.4. Importance of clients and a program of studios

The importance of including clients in the studios was recognised early on. The first objective of the studios was to study how integrated design occurs in design environments with the intention of applying lessons learnt to processes in industry. The client-architect-engineer nexus represents the core of the design environment with the client bringing brief and operational knowledge and the architect and engineer the response to this in the form of functional, aesthetic, and technical design. The client also represents a focal point in design team procurement that flows onto influencing associated design team roles such as project management, and cost control etc. A programme of successive studios was used to iteratively test the integrated design process. The initial integrated design process used was formulated through review of existing literature (refer Section 1), with the intention of refinement with each successive studio as lessons learnt through observing the studios are incorporated.

Clients with prospective projects suitable for use as case studies were sourced through the HVAC industry body partner who profiled the wider research initiative through their industry communication channels. The opportunity to explore how to improve the sustainability of building portfolios and design processes was found to be attractive to larger clients many of whom have well aligned "whole of organisation" goals around sustainability.

2.5. Initial obstacles/challenges

One of the main difficulties in setting up the IDS was to find alignment between the respective Architecture and the Engineering curricula. As much as the architecture program at the author's home institution already runs a full-semester 6-contact hours per week design studio, there is no equivalent subject in the Engineering course. Ensuring an equitable subject for Engineering students to enrol in that can be run side by side with the architectural subject has proven to be a major hurdle, in particular as the subject runs as an elective for the engineering students, whilst being part of the core program for the architecture students. The author team did not manage to arrange for the desired combined Architecture/Engineering student setup for the first semester of the IDS program. Various arrangements tested led ultimately to a bespoke "integrated design" subject in engineering being found to be the most flexible and appropriate vehicle enabling deliverables and assessments to be tweaked to align as much as possible with the architectural subject whilst still satisfying engineering accreditation requirements.

3. Main considerations for university design studios

The principles and best practices for applying integrated design based on the literature have been identified and presented in Section 1. To enable research on practical implementations of these principles an Integrated Design Studio program was formed at the authors home institution. The approach and challenges in doing this have been presented and discussed in Section 2. This section develops and discusses the main elements considered in conducting the studios.

In university design studios students not only develop and apply analytical thinking skills, which are partly acquired in previous subjects, but also abilities related to design synthesis and evaluation. Casakin and Ginsburg (2018) presented key aspects of design approach as follows:

Contextual analysis;
Problem definition and conceptual thinking;
Problem solving skills, and idea generation;
Inspiration sources and idea generation;
Precedents as inspirational sources;
Speculations on design form – morphology and façade;
Speculations on function and organization.

In addition to these key aspects, the following main consideration of integrated design were proposed, developed and incorporated into the integrated design studios.

3.1. Common goals

Key to the formulation of the integrated design process and developing a willingness in all actors to collaborate for effective innovation is the articulation of common goals (Leoto et al., 2014). These need to be equally relevant to engineers as well as architects (over individual goals by either group). Kanters and Horvat (2012) reported that it was hard to achieve common goals with all actors in integrated design process because everybody had their own specialty. A start-up workshop was seen as an important event to agree on common goals and was instigated in all studios. Ensuring all participants feel involved right from the start is crucial. Each group must respect the expertise of the other and must acknowledge the relevance of that expertise to their own problems (Simon, 1991). Moreover, each must have sufficient knowledge and understanding of the other's problems to be able to communicate effectively about them. A common goal can be an ideal building to be designed (Kynigos, 2007), it can also include quantitative/measurable outcomes defined by the client or the design team.

Before we begin the design process, the building performance attributes from different viewpoints should be fully discussed based on the client brief, this assists in avoiding confusion and conflict. Creating high performance buildings requires various stakeholders to collaborate in various stages of the life cycle of the buildings and complete clarity of the goals at the initial idea conception of the building is important for design progression. These common goals should be communicated clearly among design team members and the client, with the design team members being very clear about what they are striving to achieve for the client. Members of the design team may have their own interpretation of building performance depending on the background professional training and experience. Various viewpoints of the concept of building performance and their generic attributes are presented in Table 4.

Table 4. Viewpoints and attributes of building performance (adapted from de Wilde, 2017, 2018)

Perspective	Engineering	Process (Construction)	Aesthetic (Architecture)
View of buildings	An object	An activity	An art
Concerned with	How well a building performs its tasks and functions	How well the construction process delivers buildings	The success of buildings as an object of presentation or appreciation
Attributes	Distinguishing quality, capacity, resources saving	Cost, time, quality, safety, waste reduction, customer satisfaction	Creativity, interpretation, communication, embodiment, enchantment, movement

More details about building performance attributes in regard to an engineering perspective may be found in (Mahdavi & Wolosiuk, 2019). The generic attributes of building performance presented in Table 4 could be used for analysing client's briefs to identify building occupiers' needs and requirements, and to clearly communicate these among the design team members.

3.2. Creativity and innovation

Success of design professionals depends on creativity (Amabile & Khaire, 2008). The integrated design process should facilitate an environment where creativity and innovation can unfold. Innovation includes both idea generation (creativity) and implementation (Anderson et al., 2004). Too many, or too tight deliverables will likely overconstrain the students' and limit their ability to explore novel design solutions. Students should have "permission to fail", when searching for integrated design solutions. To develop trust relationships that facilitate creativity, proactive information exchange is essential. Communication between individuals may be seen as an analogue process that aims to share tacit knowledge to build mutual understanding. Making and solving new problems are made possible when its members share information by obtaining extra, redundant information which enables them to enter another person's area and give advice (Nonaka, 1994).

3.3. Vision, intent, strategy and culture

In the very first discovery phase: the reasons for designing the building must be considered. The studio leader could ask a direct question such as "Why do you need this building?". The integrated design process should trigger students to first reflect on why they design in a certain way, over what the immediate output might be. Everybody (i.e. the client, students, consulting architects and engineers, and academics) need to participate in engaging manner in early discovery phase. We must remove all barriers between disciples, these may be physical proximity, cultural (language, work methods, customs etc.), available time etc. Functional goals are the compulsory requirements that must be fulfilled to ensure building users are satisfied (Augenbroe, 2005). All disciplines understanding functional goals other to ensure all solutions are pulling in the same direction to consider functionality and performance at the same time. Misunderstood complexity is a threat to integrated design. Complexity should be broken into manageable simple parts to encourage understanding and integration. Open discussion with proximity and ability to communicate are important to achieve mutual understanding and value what each other does.

3.4. Balancing individual and integrated approaches

In a collaborative design each team member's viewpoint partly consists various self-serving disciplinary focus on the solution (Bahler et al., 1995). Component designers need to be willing to compromise their own disciplinary focused solutions where appropriate for the benefit of the building as a whole. The integrated design process should facilitate an appropriate balance to group thought (time interacting) and individual thought. It should articulate the desired project outcomes both from architectural and engineering perspectives, encouraging designers to understand what the "other" has to offer, and to value this in the interest of embracing and incorporating it into their own ideas.

3.5. Embrace design as an open-ended solution

In general, real-world design scenarios are open-ended and ambiguous (Abell & DeVore, 2017) as design problems are by nature wicked with no simple "true or false" response (Rittel & Webber, 1973). Solutions often unfold opportunistically and locally, as they are not necessarily resulting from a systematic and holistic search for optimal solutions (Visser, 2006). It is necessary to conduct a wide range of research to understand the system-level overview of a design problem. There is a need to make it clear to students that it is not merely about solving well-defined problems; instead, some key questions emerge as part of a multi-layered solution-finding process. Iteration and testing are often necessary and may be overlapped in time for identifying design solutions (Ulrich & Eppinger, 2015). Students should be attentive of the quote by Abell and DeVore (2017) "A core principle of design thinking is to maximize innovation through iteration".

3.6. Avoid focusing on detailed solutions too early

There is a tendency among designers to base solutions on precedent experience (Schön, 1983; Kim & Ryu, 2014). In addition, they tend to fixate their thinking on their first design ideas and variations thereof to simplify complex issues (Darke, 1979; Simon, 1991). The inherent danger of such an approach in an integrated design process relates to limiting options early on, thereby overlooking potential alternatives and neglecting valuable input from others. Both Architecture and Engineering students still need to learn how to avoid this fixation-bias and to remain open to a wider array of inputs, even if this requires them to deal with more complex concepts. Architecture students must learn to accept that integrated design will require more than the production of captivating visuals, that mainly address aesthetic aspects of the project. Engineering students must first get comfortable with supporting fast-paced and preliminary trend analysis instead of searching for in-depth, quantitative solutions. All parties need to jointly explore and discard many options early on, with results emerging from interactive collaboration. Both aesthetic and functional requirements should be met by an integrated design solution (Fasoulaki, 2008).

3.7. Encourage multi-functionality

An indicator of successful integrated design is design elements performing more than one function across different disciplines at the same time (Lovins et al., 2010). Adopting thinking approaches that consciously consider how elements of a building or design solution may be used to benefit other disciplines underpins a collaborative and integrative environment in design studios. It is also key to achieving the economical efficiencies integrated design can offer through better leveraging of building component outlay costs.

3.8. Flexible structure

One of the main points of design studios is to improve the way in which people frame problems (Brunetti, 2021). Design studios are fluid environments that rely upon the generation and exchange of ideas between all parties present, architects, engineers, clients and so on. Not only do different design disciplines work and think differently but individual designers sometimes from the same discipline have different personal styles, ways or working and communicating. It is important for any integrated design process or structure developed to be flexible and non-judging enough to cater for the different skills and often idiosyncratic ways of working different design participants bring to the collective table to extract the best input from all involved. Measures in this light may include conducting different formats of design workshop to facilitate input from all personality types, i.e. small and large group sessions and even workshops allowing off-line time for designers who prefer to sit with a particular problem for some time before suggesting solutions.

3.9. Other considerations

The other university specific items to be considered are:

Alignment between subjects: As mentioned in Section 2.4 there were difficulties getting full alignment between architecture and engineering subjects, for example varying contact hours and time commitments. This is not dissimilar to different time commitments often present in industry so representative of some of the challenges faced in industry. It was found that these could be ameliorated through the curation of studio tasks and deliverables, to be as aligned as possible while respecting differing time commitments.

Team work: This was promoted through encouragement of joint presenting, or even presentation of each other's work, time spent considering and discussing others perspectives, and learning of discipline specific terms and language. It should be recognized that no individual design team member is likely to bring the requisite cross-discipline knowledge required for integrated design to the table at the outset. Cross-discipline learning through the studios is therefore a key part of the process. This was found to be received well by students in the University context who are eager to expand their understanding of how buildings work.

Choice of students: Students particular disciplinary background is not a strong consideration in placement. Integrated design requires designers to think across others areas no matter if architecture or other engineering disciplines. It is important however that the depth of knowledge in each discipliner exists somewhere around the design table. In the cases of the studios undertaken this knowledge often sat with the consults or academics bought in to assist.

Studio facilitation: Design facilitation to guide students through process is important. Integrated design relies on big picture systems thinking and it is common for individual designers or students to lose sight of this when designing. Having a studio leader who kept sight of the bigger picture and directed designers back to it when they strayed was found to be important. The studio leader (or facilitator) also plays a role in directing the integrated design process. An example of this is asking design participants to think about an extreme architecture solution and an extreme engineering solution as a design exercise. This enabled a feel for the goalposts in design and what is important/possible before embarking on a more balanced design solution.

Human ethics: To avoid conflict of interest academic researchers need to be separate from the people undertaking the studio and assessing students in terms of accredited coursework.

Treatment of intellectual property (IP): The IP ownership was set up to sit with the creators, license was granted to all studio participants for use with undertaking to negotiate reasonable commercial terms in the eventuality of commercialisation. Copyright in student material must sit with students to allow submission of subject material for assessment.

Conclusions

The current available literature reported fundamental principles and processes of Integrated Design. Reports on the method of setting up integrated design studios in university context are however rare. This article aims to fill in this knowledge gap. To achieve this aim firstly the principles and best practices for applying integrated design were identified based on literature. The whole systems design framework, integrative design stages and process principles, have been presented. Secondly, our reflections on the approach and challenges of setting up integrated design studios in a University context were presented and discussed. Afterward the main elements to be considered in conducting university design studios were developed and documented. The Integrated Design Studio (IDS) program was set up as a testbed for integrative design processes that produce new ideas cutting across architectural and engineering domains. The IDS's were able to be setup in a way that provides win-win-win benefits for all participants (students, academics and the University, and industry). They also provide an environment for the study of integrated design practices that is mostly "risk-free" in a way that would not be possible in commercial industry environments. The challenges in practical implementations and learnings from these IDS's are expected to be presented after the completion of the research project.

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Author contributions

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