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Hex-Oid Habitat Design Challenge: Teaching Engineering Design in a Multi-disciplinary Role-Play Scenario

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Abstract

Within the ocean engineering program at the U.S. Naval Academy, formal design instruction is provided in our introductory design course, EN461, a precursor to capstone design. A useful instructional module towards this purpose is the Hex-Oid Habitat Design Challenge that provides students with a multidisciplinary design-team experience involving multiple phases of the design process and an opportunity to refine technical communication skills both within and external to the design team. Working in teams of 4-6, each team member is assigned a distinct role, e.g., Architect, Buoyancy Engineer, Foundation Engineer, etc., and each is provided a ‘skill primer’ that briefly describes their experience base, criteria and data pertinent to the design effort, and a set of strategies relevant to their role. The team goal is to design a habitat - consisting primarily of hexagonal prisms of differing weights and functional characteristics - that is aesthetically appealing, functionally sound, sufficiently buoyant, foundation adequate, and cost efficient.

Implementation of the module requires approximately two-weeks of classroom time during which students develop creative concepts, experience design team interactions, exercise their decision making skills, engage in conflict resolution, and apply various computational tools of a design engineer. During the final class session, each team presents its habitat design to a panel of volunteer faculty members and classmates who critique both the design and the team’s oral presentation.

This paper provides insights into the project tasking; the roles and responsibilities of the different design engineers; and the basic engineering considerations and computations required of the final design. It addresses typical conflict issues arising among team members and the means to their resolution, and presents elements – both positive and negative – of the typical team presentation. Achievement of project learning goals and a summary of assessment results are also discussed.

Introduction

The Hex-Oid Habitat (H-O-H) Design Challenge is an academic exercise developed for the ocean engineering program at the U.S. Naval Academy. This multidisciplinary design project involves design of an underwater habitat that, except for its roof and base, is constructed entirely of hexagonal prisms. The final structure is to be aesthetically appealing, cost competitive, functionally sound, and positively buoyant with adequate anchorage. Pedagogical goals of the project include providing students an opportunity to:

- Awaken their creative minds and exercise their decision making skills while solving an open-ended design problem;
- Experience team development and design team interactions;
- Apply various tools of the engineer’s tool kit to prepare cost estimates, project schedules, and other project information; and,
- Refine their public speaking and technical communication skills.

This paper discusses elements of the instructional module that establishes the H-O-H Design Challenge as well as the methods associated with achievement of these pedagogical goals.

Background

Within the ocean engineering program at the U.S. Naval Academy, formal design instruction is introduced in a fall-semester senior-level design course, EN461, which serves as a precursor to our capstone design course, EN462. The goal of the introductory course is to provide each student with a realistic understanding of the design process as it applies to the field of ocean engineering. Each step of the design process is illustrated through practical applications coupled with such topics as cost assessment, decision making, economic evaluation, engineering ethics, and project planning. The principal course activity, which extends over a period of seven weeks, involves student design of a timber pier which must satisfy client and NDS[1] specifications, and requires preparation of cost estimates, a construction schedule, and detailed design drawings, all presented to the client (their instructor) in the form of a written design report.

We kick-off the fall semester with a brief course introduction and discussion of the nine-step design process (after Hyman[2]) with special emphasis on Step 5: Concept Generation. To better appreciate the entire design process (cradle to grave) as well as multidisciplinary aspects of design, we then introduce our students to our instructional design module: the H-O-H Design Challenge. This smaller-scale, less-intense design exercise combines elements of design creativity, decision making, engineering and cost assessments, project planning, and technical (oral) communication. A habitat-like structure is to be designed by arranging a variety of hexagonal prisms - differing in weight and functional characteristics - upon a site map of hexagonal spaces. The overall goal is to design a buoyant structure that is aesthetically appealing, cost competitive and functionally sound, with adequate anchorage. Our H-O-H (or H_2O, for short) design exercise was modeled after the 'Delta Design' project of MIT[3], with appropriate adaptations to the marine environment.

Working in teams of five to six students, team members are assigned distinct roles, e.g., Architect, Buoyancy Engineer, Foundation Engineer, etc. Each is provided a 'skill primer', unique to their assigned discipline, that describes the designer's experience base, criteria and data pertinent to the design effort, and a set of strategies relevant to their specific role. Provision of these documents is meant to simulate the varying backgrounds and skill sets of members of a typical engineering design team in the 'real world'.

We find that two weeks of classroom time is sufficient for (i) project and role-play instruction, (ii) the student design effort, and (iii) classroom presentations of team designs. During the first hour of our 3-hour-per-week course, the instructor introduces the project and meets separately with each group of students assigned similar roles to review the relevant primer and clarify instructions. During the next 3-to-4 one-hour sessions, team members meet together to develop and refine their initial design while deciding how to resolve conflicts arising from competing criteria, e.g., establishing a balance between aesthetic appeal, functionality, and cost considerations. Early in the second week, while refining their design, each team develops a PowerPoint® presentation which is presented by the entire team – each team member presenting key aspects of their functional responsibilities - to volunteer faculty members and classmates who critique both the team's final design and its oral presentation.

Design Tasking

As an introduction to the exercise, design teams are formed and all are advised that they are members of Hex Designs, Inc., a design firm specializing in all kinds of engineered structures made of hexagonal components. Their task is to design a revolutionary underwater habitat, known in their profession as a ‘hexitat’, for use by scientists involved in studying the underwater resources of the sea. Each team member is to bring a different expertise to the project and, thus, each has different design responsibilities. After receiving a brief overview of functional responsibilities from their instructor, students decide whether they will perform the duties of Architect, Buoyancy Engineer, Foundation Engineer, Thermal Engineer, Project Manager or, in the case of six-person teams, that of Assistant Project Manager. Once team member assignments are determined, each is provided their respective skill primer. Rather than a ‘guide book’, the ‘primer’ is intended to reflect knowledge gained from many years of experience in the skill discipline. (As an example, a copy of the Project Manager’s primer is provided as an attachment to this paper.) Since each primer is meant to represent undocumented knowledge, the information provided is to be revealed only through open discussion with other team members. Each team is then presented a site map of the approximate 3750 ft^2 of marine space; the space is represented as a composite of 312 hexagonal areas (H/As), each scaled so as to be 4 feet wide and 4 feet across.

The hexitat, as designed, is to be constructed of hexagonal prisms - called hex blocks - that are made of light-weight cement composites. Each hex block is 10’ high and, standing on end, will fill exactly one 4’x4’ H/A. Principal construction units are (i) the ‘P-Hex’, a solid composite weighing about 100 pcf or 12 kips total; and, (ii) the ‘T-Hex’, weighing 9 kips and fabricated with a 2-ft diameter insulating center core. In addition, there are three auxiliary hex forms: the ‘½-Hex’, a hex block weighing 6 kips, convenient for ballasting; the ‘A-Hex’, which also weighs 6 kips and is equipped with two lock-out hatches for entering and exiting the hexitat; and, a variety of ‘E-Hex’ blocks which enclose thermal energy units of different BTU capacity and, thus, vary in weight from 10-18 kips. Finally, both the base and roof of the hexitat are to be constructed of slightly heavier composites, each 1/2-ft thick weighing 1.0 kip per H/A. Besides weight variations, each type construction unit (C/U) differs in its thermal conductivity and procurement cost - critical design information known initially only to each team’s Thermal Engineer and Project Manager, respectively. A summary of the weights and characteristics of each C/U is shown in Table 1.

Table 1. Principal Characteristics of Each Type Construction Unit

Unit Properties	P-Hex	T-Hex	1/2-Hex	A-Hex	E-Hex	Base	Roof
Weight [kips]	12.0	9.0	6.0	6.0	varies with unit size	1.0 per H/A covered	
Displacement [kips]	7.68	7.68	7.68	7.68	7.68	0.38 per H/A covered	
BTU/hr/edge loss	960	120	n.a.	720	n.a.	200	240
Size (LxWxH)	4' x 4' x 10'					varies with design	

Note: 1 H/A = 4' x 4' Hexagonal Space

Criteria-wise, the final hexitat arrangement must have 3 functional spaces: a Control Room of no less than 18 H/As; a Recovery Room, no less than 20 H/As; and, a Sustenance Room, no less than 16 H/As. Once installed, the hexitat must be positively buoyant and anchored at three points about its external boundary. Various embedment anchors, differing in holding capacity and cost, are known to the Foundation Engineer who must specify the anchorage arrangement. Finally, interior temperatures must be maintained within the scientists' comfort zone. The internal temperature of the habitat depends on the overall thermal transmission of all C/Us about the hexitat's perimeter and the total thermal capacity of the E-hex blocks installed.

Figure 1 suggests a possible hexitat design on a truncated hexagonal marine space. Although this sample hexitat does not conform to the project's specifications, for illustrative purposes, it incorporates the various types of hex blocks.

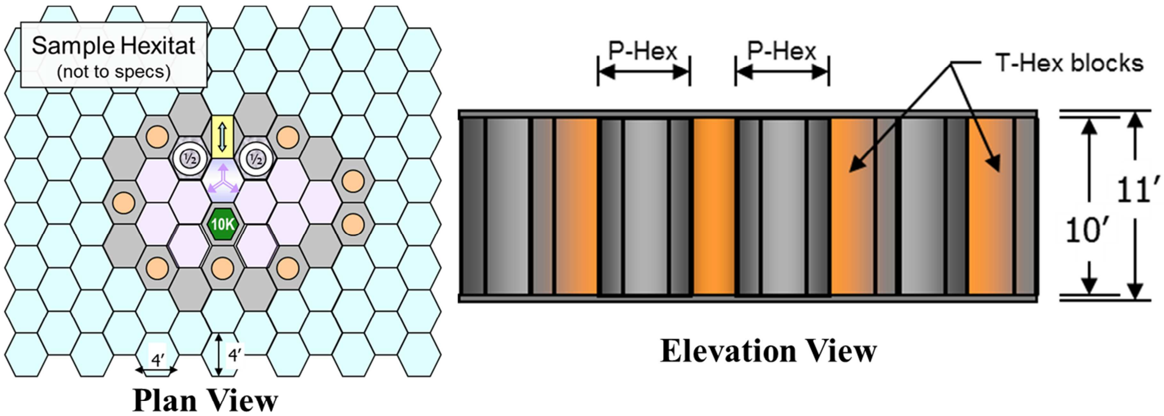


Figure 1. Sample Hexitat Design on 1248-ft^2 of Marine Space

Roles and Responsibilities

Each member of a design team has different functional responsibilities related to the design task. For example, one team member serves as the team's Architect (ARC). Their concern is with both form and function of the hexitat design. Foremost, the ARC must ensure that the hexitat's interior takes appropriate form, meets specifications, and that ingress/egress zones (between the hexitat and its environment) are sufficient in number and conveniently located. When the team submits its final design, the ARC must present a formal design sketch and discuss how and why the client will find the scientists' residence both functional and aesthetically appealing.

A second team member serves as the Thermal (Control) Engineer (TCE). The TCE must ensure that the chosen thermal energy units have sufficient BTU capacity to satisfy "comfort-zone" specifications. This team member will have some say in the hexitat's perimeter design as thermal requirements will depend on the proportion and location of the T-hex blocks applied. In the team's final design presentation, the TCE must report and validate the thermal plan.

A third team member is the Buoyancy (Control) Engineer (BCE). The BCE must ensure that the hexitat is sufficiently buoyant in seawater so as to resist anticipated hydrodynamic forces, but not too buoyant so as to cause excessive forces on the anchored foundation. As necessary, the BCE may suggest that appropriate ballast (in the form of additional P-hex or ½-hex blocks) be added to the structure. During client briefings, the BCE must report and defend (if necessary) the computations of the hexitat's net buoyant force and the locations of its center of gravity and its center of buoyancy.

Yet another team member is designated the Foundation (Anchor) Engineer (FAE). Their main concern is to ensure that the hexitat, as designed, 'holds position' in view of its buoyant nature. The FAE must select appropriate anchor points for affixing the hexitat to the seafloor, calculate anticipated mooring line tensions, and size each anchor accordingly. When the team submits its final design, the FAE must attest to the hydrodynamic stability of the hexitat structure by reporting the anticipated load on each of three anchors and their degree of safety, i.e., ratio of anchor holding capacity to its anticipated loading.

Finally, a fifth team member serves as Project Manager (PMR) and, when assigned, the sixth team member serves as Assistant Project Manager (A-PMR). Their principal concerns will be interpretation and reconciliation of performance criteria, and maintaining effective communications and negotiations between team members and with client representatives. These team members must also focus on cost and schedule. Among their objectives are to keep costs and time-to-build at a minimum, but not at the expense of hexitat functionality. In addition, the PMR and A-PMR are responsible for (1) finalizing the team's presentation to the client; (2) ensuring that each team member's contributions are properly reported; and, (3) reporting their own calculations of (estimated) cost and time to implement the team's design.

Basic Engineering and Project Management Computations

Among the basic engineering calculations to be demonstrated are thermal efficiency, net buoyancy, mooring line forces, project cost and duration. These computations are the responsibility of the TCE, BCE, FAE, and PMR/A-PMR, respectively. The various 'primer' documents provide specifics of the related criteria and include simple illustrations of the calculations to be made.

For example, the BCE's primer advises that the hexitat must have a minimum 60-kip net positive buoyancy to ensure in-situ stability. As such, for each design alternative, the BCE must determine its in-water weight. Also, the BCE will need to provide the FAE with approximate locations of the centers of gravity and buoyancy of each alternative so that the latter may calculate mooring line forces. These centroid values must necessarily be recomputed each time the team's design is modified. To facilitate computation, the BCE is encouraged to establish an appropriate coordinate system for the marine space so as to define numerically the X&Y centroid of each H/A, and develop a spreadsheet similar to that illustrated in Table 2. Then, by overlaying a schematic of each design alternative on the coordinate space, every H/A can be identified as to the hex block applied. With a properly formatted spreadsheet, net buoyant force and both centroid locations are readily determined simply by re-designating the 'hex type' and 'hex weight' for any H/A altered.

The PMR primer provides information as to activity durations, sequencing and costs. It indicates that the costs of fabrication and installation are driven in part by (1) the number and type of each hex block assembled, (2) both the in-air and buoyant weight of the entire structure, and (3) the number and size of the energy units (E-hex blocks) and anchorages applied. During 'primer review' with team PMRs, the instructor will demonstrate cost estimate computations using a spreadsheet template (see Table 3), not unlike one that might be used by a professional cost engineer. To affect efficient computation of project costs, the PMR (or A-PMR) needs but prepare a similar spreadsheet and enter the 'TBD' (to-be-determined) quantities of each design alternative. The automated cost ('AC_*') values are instantly updated for comparative purposes.

Table 2. Sample 'BCE' Computation Table for Centers of Gravity and Buoyancy

		Center of Gravity Computations					Center of Buoyancy Computations				
H/A #	Hex Type	Hex Wt* [kips]	X-Dist	W_X-Mom	Y-Dist	W_Y-Mom	F_B [kips]	X-Dist	F_{BX}-Mom	Y-Dist	F_{BY}-Mom
1	P	14	2	28	6	84	8.44	2	16.88	6	51
2	T	11	2	22	10	110	8.44	2	16.89	10	84
3	A	8	2	16	14	112	8.44	2	16.89	14	118
4	T	11	5	55	4	44	8.44	5	42.22	4	34
5	(FS)**	2	5	10	8	16	8.44	5	42.22	8	68
6	(FS)	2	5	10	12	24	8.44	5	42.22	12	101
7	P	14	8	112	2	28	8.44	8	67.55	2	17
8	(FS)	2	8	16	6	12	8.44	8	67.55	6	51
9	(FS)	2	8	16	14	28	8.44	8	67.55	14	118
10	P	14	8	112	18	252	8.44	8	67.55	18	152
11	E	18	11	198	8	144	8.44	11	92.88	8	68
12	(FS)	2	11	22	12	24	8.44	11	92.88	12	101
◆	◆		◆	◆	◆	◆		◆	◆	◆	◆
29	T	11	23	253	8	88	8.44	23	194.21	8	68
30	P	14	23	322	12	168	8.44	23	194.21	12	101
	Sum W=	250.0	Sum W_XM:	2933.0	Sum W_YM:	2450.0	Sum F_B=	Sum B_XM:	2990.6	Sum B_YM:	2534.4
			CG-X [FT]=	11.73	CG-Y [FT]=	9.80	253.4	CB-X [FT]=	11.80	CB-Y [FT]=	10.00

*Includes weights of hex-prism (when present), base, and roof encompassing the H/A; ** Functional (or open) space internal to the hexitat)

Such automated calculations for buoyancy and project costs not only provide useful project information but also serve to demonstrate the benefits of spreadsheet modeling for alternative assessments. The ability to efficiently modify and update pertinent design and cost information is not just desirable but necessary in a fast-paced project such as this.

Table 3. Sample 'PMR' Cost Estimate Template

				Procurement Costs		Assemblage Costs		Installation Costs		Item Total[4]
CAT	ITEM	Quantity	Unit	Unit Cost[2]	Subtotal[3]	Unit Cost	Subtotal[3]	Unit Cost	Subtotal[3]	
1.	**Site Preps**									
	Mobilization	5	days					$5,000	$25,000	$25,000
	Demobilization	5	days					$7,500	$37,500	$37,500
2.	**Hex-Oid Fab/Del**									
	A-Hex	(TBD)	ea.	$500	(ACP)	$50	(ACA)			(ACT)
	E-Hex (24K BTU)	(TBD)	ea.	$1,800	(ACP)	$300	(ACA)			(ACT)
	E-Hex (36K BTU)	(TBD)	ea.	$3,000	(ACP)	$400	(ACA)			(ACT)
	P-Hex[2]	(TBD)	ea.	(TBD)	(ACP)	$50	(ACA)			(ACT)
	T-Hex[2]	(TBD)	ea.	(TBD)	(ACP)	$50	(ACA)			(ACT)
	½-Hex[2]	(TBD)	ea.	(TBD)	(ACP)	$50	(ACA)			(ACT)
3.	**Hex-Oid Pads**									
	Base	(TBD)	H.U.	$30	(ACP)					(ACT)
	Roof Fab	(TBD)	H.U.	$40	(ACP)					(ACT)
	Roof Lift	1	L.S.			$15,000	$15,000			$15,000
4.	**Anchorage**									
	Anchors - 40K	(TBD)	ea	$45,000	(ACP)			$15,000	(ACI)	(ACT)
	Anchors - 55K	(TBD)	ea	$55,000	(ACP)			$20,000	(ACI)	(ACT)
	Mooring Lines	3	ea	$5,000	$15,000			$15,000	$45,000	$60,000
5.	**Hexitat Unit**									
	Mob/Trans	(TBD)	tons					$200	(ACI)	(ACT)
	Installation	1	days					$15,000	$15,000	$15,000
	Inspection	1	days					$15,000	$15,000	$15,000
								Project Total[5]:		$ (ACT) .

Note (1): "Gray Cells" are non-entities/not applicable; TBD quantities/costs are 'To Be Determined'.
Note (2): Unit procurement costs (TBD) depend on quantity ordered. **Note (3):** Subtotal = Quantity * Unit Cost.
Note (4): Item Total = Sum of Row's Subtotals. **Note (5):** Project Total = Sum of Item Totals.

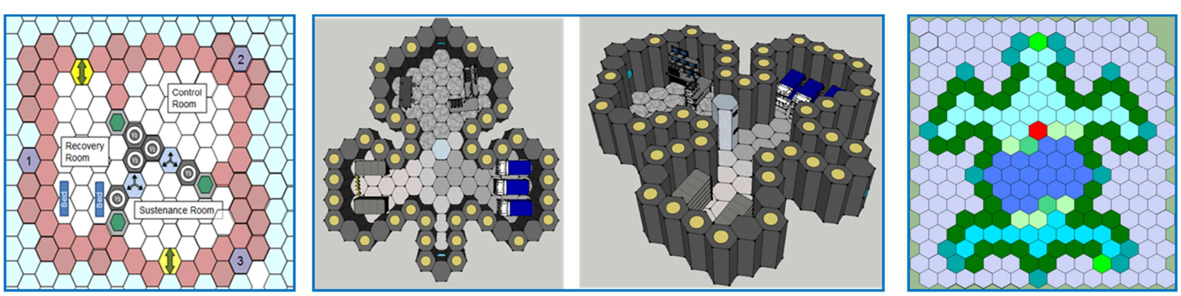
Conflict Issues for Resolution

Given the open-ended nature of our H-O-H design project, there are a near infinite number of design possibilities. In addition to deliberations regarding aesthetic form and arrangement of functional spaces, typical conflicts that need be resolved are:

- How large a ‘footprint’ is appropriate? A smaller footprint correlates with less construction units and, therefore, less project cost and time. However, the absence of sufficient internal ‘net buoyant’ space may result in a structure with inadequate buoyancy and, therefore, insufficient hydrodynamic stability. Contrariwise, too large a footprint might result in too buoyant a structure and excessive anchorage costs. Also, an abundance of internal space will increase thermal conductivity through the hexitat’s floor and roof necessitating more expensive, higher-capacity thermal units.
- How much thermal capacity is desirable? Increasing the proportion of the more expensive thermal blocks about the structure’s perimeter will increase procurement costs but decrease the need for the higher-capacity thermal units.
- How many of each type block should be ‘ordered’? Due to price breaks in the unit cost function of each type hex block, adding a few more of one type (or another) might reduce overall cost of the hexitat.
- What composition and arrangement of the anchorage system is appropriate? Only perimeter P-hex blocks are structurally adequate for attachment of mooring lines, and the selection of attachment points will affect mooring line forces. Therefore, a cost-efficient anchorage system may necessitate relocating P-hex and T-hex blocks about the hexitat’s perimeter. Given that at-sea installation and anchorage costs comprise more than 50% of total project costs, slight alterations of block type and position can be cost advantageous.

Each of these design issues, among others, is encountered by every design team. The significant variation in parametric values of different team designs is suggestive of the challenge confronting each team as they attempt to resolve such conflicts. In the past year, among ten hexitat designs, net buoyancy varied from 60.5 to 191.3 kips; total project costs ranged from $432K to $712K; and, whereas most designs included an abundance of thermal blocks about the perimeter, one design did not specify any.

Figure 2 provides but three examples of the creative design forms resulting from team deliberations in past years. Due to the various criteria, some being qualitative (e.g., ‘aesthetics’), there is no algorithm to determine an ‘optimal design’. Rather, a successful outcome depends on the team’s ability to defend its ‘conflict resolution’ rationale when presenting its design to the client.



The Blue Hen | The Clover | The Turtle

Figure 2. Creative Hexitat Designs by Student Teams

Team Development and Interactions

For most, the H-O-H Design Challenge is the first opportunity to participate in a design competition involving a team of more than two students. Given the multidisciplinary and fast-paced nature of the challenge, i.e., to conceive, resolve, and present a hexitat design in less than two-week's time, team members are soon to realize their dependence on the performance of their teammates. Team meetings must be scheduled outside of class time, information must be shared, and data updated in an efficient manner. Students must hone their communication skills and readily adapt to other interpersonal team activities (e.g., shared leadership, goal setting, participation and collaboration, conflict management, etc.) that make for successful team development and performance. Conflict resolution is a necessary evil, but team members are keen to realize that mutual cooperation and accountability is a means to balancing the competing interests of each discipline. Fortunately, most soon learn that clear, complete and responsive communication and the efficient synthesizing of information are keys to team success.

Design Presentation and Assessment

In the end, each design team (typically three or four teams per course section) must prepare and present a 15-minute PowerPoint® presentation to their class. The challenge is to convince their client (course instructor) that the team's hexitat design satisfies specifications and provides the best overall balance among the selection criteria, i.e., aesthetics and functionality, thermal adequacy, buoyancy and foundation sufficiency, cost and schedule.

The course instructor(s), volunteer faculty, and members of other design teams all participate in a verbal critique of the presentation as to (i) the reasonableness of the design with respect to the specifications, (ii) the presentation skills of each team member, and (iii) the overall style of the presentation, i.e., flow and clarity of visual aids. Course instructors also review and evaluate each team's technical computations, submitted as separate documentation. A 50-50 weighting of the technical proficiency of the design and the team's oral and written presentation skills results in a final project grade.

As one would expect, presentation skills vary among team members and from team to team. Nevertheless, useful feedback is provided to each student with respect to their public speaking abilities. Clearly, team members showing obvious enthusiasm for team dynamics and their own design contributions receive higher presentation scores. The accuracy and formatting of computational results also vary among team members and teams. The most frequent technical errors result from misinterpretation of the specifications or from misinformation shared among team members. Lessons learned from this team design experience are the importance of giving attention to detail, individual accountability, and ensuring adequate two-way communications.

End-of-semester course evaluations indicate that many students - if not most - find the H-O-H Design Challenge, while demanding, to be an enjoyable experience. Reflecting on this past year's course evaluations, more than 65% of 50 students indicated that elements of the two group projects (hexitat and timber pier) provided the most effective learning experiences of the course, clearly trumping class lectures, in-class problem solving, homework, and exams. As to the effectiveness of the hexitat project in providing students with appreciation and understanding of the design process, students gave it an average rating of 4.04 on a five-point scale. This score was slightly better than the more extensive seven-week timber pier project which rated a 3.94.

Finally, among student responses to the direct query, “What was the most effective learning experience and why?,” were that the hexitat project “allowed us … to work out kinks in project ideas and goals” and that it “was very good …[we] learned a lot about the design process.”

From a pedagogical viewpoint, perhaps an even better ‘result’ is that by introducing the H-O-H Design Challenge early in the semester, it enables us to reference the hexitat design experience as we discuss the various steps of the design process. By having a recent and common design project example to which all can relate, the stage is set for an effective semester of design instruction.

Conclusions

Our Hex-Oid Habitat Design Challenge is a fast-paced, open-ended design experience. While having minimal impact on course schedule, it provides a useful introduction to materials covered later in our introductory design course, EN461, and in capstone design. Seemingly light-natured, the ‘Challenge’ has proven its meddle in exposing our students to a multidisciplinary design experience that exercises their creative abilities, exposes them to design team interactions, introduces some basic tools of the design engineer, and provides opportunity to bare and refine their public speaking skills.

For those faculty members of other institutions interested in learning more of the tasking and contents of the various skill primers, a complete set of our documentation will gladly be provided to whoever might be interested. Indeed, we’ll welcome your interest and look forward to sharing our H2O design experiences with yours.

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Acknowledgements

The authors wish to express appreciation to professors L. Bucciarelli and H. Einstein of M.I.T. who posted their Delta Design project on the internet; such was the impetus for creating our own “H-O-H Design Challenge”.

Attachment

A. H-O-H Design Challenge: “Project Manager Primer” (see following 3 pages)

Project Manager Primer

• **Introduction:** As Project Manager, your main concerns are cost and schedule, overall interpretation and reconciliation of performance specifications, and negotiations with the contractor and client. Your primary objectives are to minimize cost and time-to-build, but not at the expense of quality. When your team submits its final design, you must report the cost and time that you estimate is necessary to build the hexitat.

• **Fabrication and Installation Overview:** The hexitat will be built on land and then transported intact to the installation site. The first evolution will involve preparation of the assembly site followed by fabrication of the base and roof. The various hex-block units will then be attached to the base. A single crew can install 4 typical hex-block units (P-Hex, T-Hex and 1/2–Hex blocks) per day; two crews are available and may work simultaneously. Assemblage of A-Hex and E-Hex blocks will take slightly longer (see below). With all hex blocks attached to the base, the roof will then be raised in a four-crane lift operation and set atop the vertical-standing hex-blocks. Once in place, bonding and curing of the roof to the hex blocks will require five days.

While the hexitat is being readied for transport, the hexitat's anchors and anchor chains may be installed on the seafloor. Mooring lines can then be attached. Once on site, the hexitat may be attached to the free end of each mooring line and winched down into its operational position.

A final inspection, facilitated by divers, will consume one-half of a working day, although a full day will be required for both the inspection and proper documentation. Assuming a successful installation, the hexitat will be declared "fit for habitation." Demobilization, including return of all installation vessels and equipment to port, will conclude the project.

• **Estimating Project Schedule:** Estimating time-to-build is inexact, due to differing environmental conditions at the assembly and installation sites. Based on past experience involving other underwater projects, the fabrication contractor has provided the following information regarding various phases of installation (some of which has been previously summarized in Section 1.2.)

- Procurement (fabrication and delivery to site) of the various hex blocks requires 45 days.
- Site preparations (for fabrication of the base and roof) should take 5 days and may take place during procurement. Base and roof fabrication will each take 30 days and may be accomplished concurrently.
- Assemblage of the various hex blocks (on the base) can be accomplished in accordance with the adjacent table:

Estimates of Assemblage Durations

Component	Unit	Crew Type	Daily Output (per crew)
A-Hex	Each	F-6	1
E-Hex	Each	F-6	0.25
P-Hex	Each	F-6	4
T-Hex	Each	F-6	4
1/2-Hex	Each	F-6	4
Roof Lift	Unit	C-4	1

Note: Two F-6 crews (supervisor, 4 labs, crane) are available.

- One day will be required to lift the roof structure atop the hex assemblies, followed by five days to securely attach (bond and cure) the roof to the various hex blocks.
- Five days will be required to prepare and transport the hexitat to site.
- Installation of the anchorages can take place any time after the five days of site preparations. Durations of at-sea installation activities are estimated as follows:

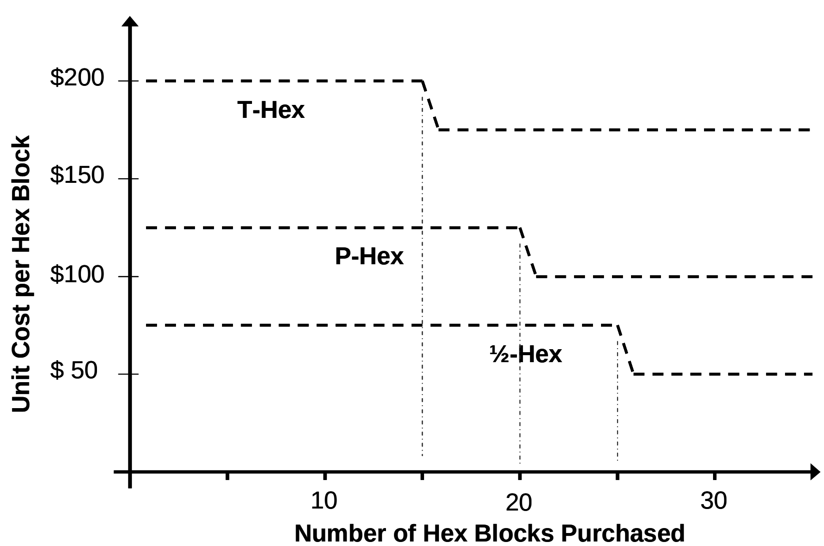
Estimates of Activity Durations for Hexitat Installation

Task	Unit	Crew Type	Daily Output (no. per day)
Anchor	Each	B-76	2
Mooring Line	Each	B-76	2
Hexitat	Ttl	B-76	1
Dvr Inspection + documentation	Ttl	D-6	1
Demob	Ttl	F-3	**0.2**

- The final evolution is project demobilization (return to port, disassembly of project site) which should be completed in five-days' time.

• **Estimating Project Costs:** Project expenditures will consist of (1) procurement (i.e., fabrication and delivery) of the various hex blocks; (2) expenses associated with site preparations; (3) fabrication of the base and roof structures; (4) assembly of the hexitat facility; (5) mobilization and transport of the completed facility; (6) procurement and installation of the anchored moorings; (7) at-sea charges for hexitat installation and inspection; and, (7) finally, demobilization expenses.

- The cost of hex blocks varies by type of block and quantity purchased, as suggested in the following chart. For example, a single T-Hex block costs $200 for fabrication and delivery. However, quantity discounts are available. If 16 or more units of T-Hex blocks are purchased, the unit cost of each will be $175. Quantity discounts for P-Hex and ½-Hex blocks are also available. The procurement cost of each A-Hex block is $500, with no discount available.



- Procurement of E-Hex blocks depends on their BTU capacity as per the following table:

E-Hex Unit Procurement & Assemblage (to base) Costs		
BTU Capacity [BTU]	Procurement Cost [$/unit]	Assemblage Cost [$/unit]
12K	800	200
24K	1800	300
36K	3000	400
48K	4200	500

- Site preparations are estimated to cost $5,000 per day.
- On-site fabrication of the base and roof are $30 and $40 per HU, respectively; these prices include all charges for MEL (i.e., material, equipment and labor).
- Assemblage (to the base) of each A-Hex, P-Hex, T-Hex and ½ Hex is $50/unit, MEL. Assemblage (to base) of E-Hex blocks is reflected in the previous table.
- Labor and equipment to raise the roof is estimated to cost $15,000.
- Attachment of each hex block to the roof is estimated to cost $50 per unit, MEL.
- Mobilization and transport of the completed hexitat to the installation site will cost $200/ton based on total hexitat weight.
- Costs for procurement and installation of the anchored moorings are reflected in the following table:

Anchor Mooring Procurement & Installation Costs			
Anchor Type/Size	Holding Capacity [lbs]	Procurement Cost [$/unit]	Installation Cost [$/unit]
Embedment, 20 Kip	20,000	$25,000	$10,000
Embedment, 40 Kip	40,000	$45,000	$15,000
Embedment, 55 Kip	55,000	$55,000	$20,000
Embedment, 72 Kip	72,000	$65,000	$25,000
Mooring Line P&I Costs, per line (i.e., attachment pt)		$5,000	$15,000

- At-sea costs for installation (i.e., attachment and winching) of the hexitat and final diver inspection (including documentation) will cost an estimated $15,000/day.
- Demobilization costs are estimated to be $7,500/day.

- **Design Communication:** As project manager (PMR), you should be prepared to present your team to the client, define each member's responsibilities, and layout the plan for your design briefing. While each team member is expected to take part in your team's presentation and contribute to its compilation, as PMR, you should be prepared to present your cost and schedule information using an appropriate cost data sheet and a Gantt chart that illustrates anticipated project progress.