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From the Printer to Post: Evaluating the Feasibility of 3D-Printed Modular Barracks for Deployed Environments

December 2025

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ABSTRACT

A vital element of an expeditious military is the ability to quickly deploy troops to austere and dynamic environments. Living quarters are an essential component of deployment. Currently, Department of Defense (DoD) branches rely on traditional solutions, such as temporary forward deployed barracks huts (B-Huts), containerized living units (CLUs), or Tent Extendable Modular Personnel (TEMPER), a modular, soft-walled, aluminum-framed tent. While practical, these frameworks fail to meet the demands of survivability and durability, force protection, and livability. Additionally, these options impose a significant logistical burden that requires shipment of construction material, engineer and transportation workforce, and associated time costs that strain operational and sustainment processes. This research conducts a qualitative comparative evaluation which analyzes the survivability, logistical efficiency, equipment lifespan, and habitability of conventional housing types in comparison to additive manufacturing (AM) construction. The study determined that as AM technology matures, its advantages are in structural resilience and progressive supply chain, which has the probability to reshape the DoD in future expeditionary infrastructure.

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ACKNOWLEDGMENTS

I would like to thank my advisors (Kelley Poree and Jonathan Lipow), Elizabeth and Michael from the Graduate Writing Center, Megan Kreiger from U.S. Army Engineer Research and Development Center, and my fellow Department of Defense Management peers. Their insight and help are what made this research possible. Their patience and expertise were vital throughout the assembly of this paper.

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	three-dimensional
AC	additive construction
ACES	Automated Construction of Expeditionary Structures
AM	additive manufacturing
AO	area of operations
B-Huts	barracks huts
CERL	Construction Engineer Research Laboratory
CHUs	containerized housing unit
CLUs	containerized living unit
DoD	Department of Department
ERDC	Engineer Research and Development Center
FOB	forward operating base
GAO	Government Accountability Office
HN	host nation
IOT&E	initial operational test and evaluation
ISO	International Organization for Standardization
MCDA	multi-criteria decision analysis
MILCON	military construction
MOE	measures of effectiveness
QCA	qualitative comparative analysis
R&D	research and development
RPG	rocket-propelled grenade
SME	subject matter expert
TEMPER	Tent Extendable Modular Personnel
TTPs	tactics, techniques, and procedures
UFC	United Facilities Criteria

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DISCLOSURES

Professor Poree and I agreed that I would use generative AI in a limited way, to improve conciseness, and clarify topic sentences to ensure flow of subsequent paragraphs. I used ChatGPT 5.1 to improve grammar and punctuation, help revise or tighten wording, organize research questions and brainstorm ideas, refine thesis outline and chapter structure, formulate email drafts to the Army Corps Engineer Research and Development Center (ERDC), generate complex charts using organically gathered data, reformat collected material for section flow, understandability, improve academic tone, lessen redundancy, and check for consistency of terminology. Examples of prompts I used are "Help me structure this sentence better: [insert sentence]" and "Can you identify repetitive statements?"

To decrease risk of transgressions when using AI, I was mindful of each sentence written, never solely relied on AI, sought research guidance from advisors, and thought critically.

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I. INTRODUCTION

This study is inspired by a young soldier and social media influencer, Briyana Taylor (2024), who went viral to transform her standard-issue military barracks room into a faux luxury master bedroom. Her creativity and initiative resonated with thousands of service members, earning recognition from senior leaders and prompting her to offer similar services to transform others living quarters in a similar manner across the force (Cortes Gonzalez, 2025). Her story highlights a broader desire among soldiers for improved living conditions, one that goes beyond aesthetics and speaks to morale, mental health, and increased quality of life (Taylor, 2024). In this context, additive manufacturing (AM), particularly large-scale three-dimensional (3D) concrete printing, presents a compelling solution to overall improvement for the military. Brooke Becher (2024) states AM involves joining geometric objects, shapes, and textures from 3D model data, created by an "industrial-sized printer that develops one tiny layer at a time" (para. 6). In the Department of Defense (DoD) (2021) *Additive Manufacturing Strategy*, "AM can be used to: build parts that cannot be made any other way; uniquely combine materials; produce obsolete parts; rapidly prototype; create tools and specialized job aids" (p. 4). The advancement of AM is slowly becoming an important tool in the modernization of defense systems; the objective in obtaining this technology is to enhance the protection and soldier readiness (Department of Defense [DoD], 2021).

Brooke Bauguess (2020) wrote of an innovative additive construction (AC) structure that the U.S. Marine Corps' fabricated to experiment with expeditionary construction capabilities. They created large vehicle hides at Camp Pendleton, in collaboration with ICON to investigate how well they are equipped in a crisis response effort (Bauguess, 2020). AM is a force multiplier for defense modernization by enabling rapid production and customizable manufacturing. The rapid construction of prototypes increases readiness to meet on-demand opportunities and helps modernize current defense systems. Luckily, it results in a faster acquisition process, and in turn, it allows AM to provide an opportunity to transform battlefield logistics through rapid infrastructure deployment through modernization and bringing item fabrication directly to where it is needed. A direct and practical application of this technology benefits all DoD branches is experimenting with military housing, a project of low risk and high return potential.

A report from Gordian (2024) researched military housing, and it shed light on the critical state military housing currently is in. According to Gordian's research, 63% of military families live in military housing, and 58,000 of DoD's base housing units, 43% of the DoD's total housing, are old and require extensive repair (para. 3, 7). Gordian estimates indicate using traditional military construction (MILCON) practices and budgets would need 30 years and $20 billion dollars to complete the required renovations and improvements to bring these units up to modern standards (para. 7). However, Gordian's analysis does not account for the continued deterioration of the other military housing units in the meantime (para. 8). Also, a Government Accountability Office (GAO) (2023) report found that poor barracks conditions directly affect soldier performance and mental health, though DoD lacks sufficient data quantifying readiness effects (p. 19). In short, dilapidated buildings impact the DoD beyond financial cost; poor living conditions diminish service members' quality of life, morale, and readiness.

Theo Burman (2025) shed light on AM projects that have proven successful in controlled settings, but there is a lack of AM research in austere and deployed conditions, where infrastructure and transportation resources are limited (para. 1). The innovative, and recently opened, 3D-printed barracks located in Fort Bliss demonstrated successful after its year-long pilot program (Burman, 2025). For that reason, Burman (2025) states the experimentation of AM in combat situations is the next step for such technology (para. 11). My research evaluates the potential of AM for deployed military living quarters over the next few years, with a focus on discussing scalable, resilient infrastructure that directly supports Army mission readiness and enhances soldier QOL.

Advancements in AM, particularly large-scale 3D concrete printing, offer a potential alternative for modular barracks that are faster to build and more sustainable (Becher, 2024; Al-Chaar et al., 2021). While entities like the Army Corps Engineer Research and Development Center (ERDC), alongside private firms, have shown AM's viability in peacetime (or garrison) construction, there remains the question of what technology can feasibly do in forward operating bases and other expeditionary settings (Al-

Chaar et al., 2021, p. 2). This thesis explores whether AM can outperform traditional systems' survivability, logistical footprint, equipment lifespan, and habitability's role in forward operating base construction.

Currently, traditional types of temporary living quarters in deployment settings are Tent Extendable Modular Personnel (TEMPER) tents, barracks huts (B-Huts), and containerized living units (CLUs), whose capabilities limitations are high cost, project timeline delays, and lower morale. These options are labor-intensive, logistically troublesome, and often fail to ensure survivability, durability, and habitability.

A. PURPOSE

The objective of this study is to evaluate the feasibility of using large-scale AM, specifically 3D printing, to construct modular barracks in austere, resource-limited regions to improve the quality of life (QOL) for deployed or temporary soldiers. To ensure the reader fully understands the definition of an austere environment, per Congressionally Directed Medical Research Program (CDMRP) (n.d.) defines it as an environment implies locations with limited or nonexistent infrastructure. So, this study is to provide the DoD with research on various housing options for deployment modular barracks by evaluating several factors: (1) structure survivability to evaluate strength, (2) logistical requirement to build and sustain housing quarters (3) the lifespan of the equipment, (4) habitability to support soldier safety, comfort, and psychological needs to analyze the limitations between AM to other conventional housing options. AM utilization has yet to move beyond the pilot phase in its application outside of controlled environments, utilized in limited resource areas, and enhanced soldier quality (McBirney & Burton, 2022). It offers a potential alternative for constructing modular barracks that are faster to build, more sustainable, and better suited for austere operational conditions. The goal of this study is to inform the Army of AM-based modular barracks effectiveness by comparison to what it currently utilizes. In the end, the military's goal is to modernize and sustain mission readiness while reducing dependence on time- and labor- intensive construction methods, focusing on how these structures perform in current and projected operational environments over the next five years as AM becomes a more viable and popular option.

B. RESEARCH QUESTIONS

The primary and secondary research questions for this thesis are defined as:

- **Primary:** Which deployed living quarter structure (tents, containerized housing units, B-Huts, or 3D-printed modular barracks) best sustains soldier readiness and operational effectiveness under austere and expeditionary conditions?
- **Secondary:** To what extent do differences in survivability, logistical sustainment, service lifespan, and habitability among TEMPER tents, CLUs, B-Huts, and 3D-printed barracks influence soldier welfare and mission readiness in contingency operations?

C. SCOPE AND LIMITATIONS

The research method utilized to evaluation applied in this report is comparative qualitative analysis between AM and conventional construction methods (e.g. TEMPER tents, B-Huts, and CLUs). The research information is primarily scoped to company- or platoon- level housing requirements in deployed or contingent environments. The austere, expeditionary settings such as forward operating bases (FOBs), combat outposts, or temporary installations. It covers five key feasible dimensions: structural durability, construction speed, cost-effectiveness, logistical efficiency, and environmental adaptability. The thesis will leverage existing data from military publications, engineering reports, and complete AM demonstration projects.

This study is subject to several limitations:

- **User-Centered Metrics:** The research does not include direct input from service members or end user suggestions regarding quality-of-life improvements. It focuses on limited subject preference with focus on practicality due to its austerity constraint.
- **Operational Testing:** No field testing is conducted in this research; therefore, the assessment is only based on existing prototype information, existing literature, and academic reports.

- **Technology Maturity:** AM has advanced, however it remains immature with many technologies and systems still in prototype or early production stages and may not be widely deployable under current force structure constraints.
- **Budget and Policy Forecasting:** The study does not predict or assume future funding decisions, acquisition programs, or doctrinal changes beyond existing published guidance.

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II. LITERATURE REVIEW

This section reviews literature relevant to deployed military housing and emerging construction technologies that may be used as secondary data for research purposes, but most importantly, it establishes the foundation for this study. It examines doctrine and standards governing current Department of Defense (DoD) contingency construction. It outlines characteristics and limitations on conventionally deployed living quarters and evaluates additive manufacturing (AM) capabilities as a potential alternative for soldier housing in the near future. The chapter will discuss research conducted by the Engineer Research and Development Center (ERDC) and industry partners, compares housing performance across housing systems, and identifies gaps in research.

A. CURRENT DEPARTMENT OF DEFENSE BARRACKS STANDARDS AND DOCTRINE FOR CONTINGENCY ENVIRONMENTS

Department of the Army contingency construction doctrine ATP 3.37.10 *Base camps* (Department of the Army [DA], 2017) is a military doctrine that goes over techniques and considerations needed to establish standards for base camps to provide guidance for tactics, techniques, and procedures (TTPs) in deployed environments (p. iv). In the doctrine its states the Army and Marines plan, design, construct, guide operations, and closure of base camps as primary preference to manage temporary and semi-permanent living and operational facilities during contingency operations (p. 1-5–1-6). A base camp serves as an intermediate staging base, as known as a FOB and sustainment/logistics base. The base size for a platoon is ~50 and for a company it is ~100 personnel (p. 1-5). The regulation discusses base camp duration and design standards by facility type, depending on the organizational goal on arrival to its austere, operational area (DA, 2017). It helps acquisition professionals understand military requirements to generate appropriate options for DoD leaders to employ.

1. Construction Standards

According to *Base Camps* (DA, 2017), construction standards are for buildings and infrastructure depending on the life span of the base camp. Typically, enduring construction is not used in the contingent phase of a deployment but are special circumstances when semi-permanent construction can be used in the initial or temporary construction if the areas of operation (AO) site or mission requires it (p. 1-5). The description of the stages is as follows (DA, 2017):

- **Initial:** It is facilities with minimum capabilities, proposed for speedy use upon arrival by personnel in theater for up to 90 days and not intended to be used for longer than 6 months. It requires minimal engineer effort for initial force presence and operational activities until logistical support can sustain engineer resources.
- **Temporary:** military construction intended to be low cost, expeditious, and build using locally available materials. Temporary construction's life expectancy of 5 years or less as low-affordable buildings/facilities to accommodate lodging for a moderate duration of time. The intention of these buildings is to strengthen the efficiency of operations and reasonably improve the quality of life for occupants.
- **Semi-Permanent:** Facilities with the purpose of a lasting presence, with a semi-permanent capability to serve for a life span of <10 years. These structures, if taken care of with proper maintenance and repairs, have a life expectancy of ~25 years. Planning requires consideration of semi-permanent structures with expeditious construction operations and material availability.

The *Base Camps* (DA, 2017) standards are intended to ensure that facilities remain in use for a duration of time, most likely, that justifies taxpayer expenditure, while preventing overstayed use of housing types that may degrade conditions and endanger occupants.

2. Department of Defense Contingency Construction Doctrine

The *Unified Facilities Criteria* (UFC) (DoD, 2019) is the document which provides planning, design, structure, upkeep, restoration, and modernization of DoD facilities. According to the document, "alternative materials, design and methods of construction and equipment that do not lessen quality, strength, effectiveness, fire resistance, durability, and safety. In these instances, formal exemptions are not required" (p. 5). An example of an alternative material is a substitute concrete, made up of material mixture that is equivalent to or stronger than conventional concrete (Al-Chaar et al., 2021). The use of this non-conventional technology was conducted by the Army ERDC Construction Engineer Research Laboratory (CERL) in a controlled environment, which conducts the types of studies that inform research and guide improvements to benefit the military in expeditionary operations (ERDC, n.d.). Due to additive construction (AC) infancy and lack of historical data, in comparison to traditional construction, it is important to properly evaluate and document its performance and design perspective. The Army, as Theo Burman (2024) wrote in Newsweek, successfully built AM barracks on Fort Bliss with the help of several entities such as ERDC and ICON (para. 2, 6). Also, in *New Innovative Army effort builds 3D-printed barracks* written by Alyx Riebeling (2024) states these barracks are the first of its kind in the world to have gone through extensive review and meet specifications through the UFC which addresses general building requirements (para. 5). ERDC plays critical role in review of first 3D printed Army barracks article by Sophia Espinosa (2025) also discusses the collaboration between ERDC-CERL provided oversight to review for the 3D-printed wall systems during the project (para. 1). Espinosa expresses how ERDC-CERL alongside DoD, academic institutions and private sector partners has been at the forefront of AC research since 2014 to help meet the unique needs of military construction (para. 11-12). Therefore, as the Army continues to research the future of construction, ERDC will continue to evaluate 3D concrete printing while evaluating safety to best meet the highest standards for warfighters and structural integrity (Espinosa, 2025, para. 15).

3. Implications for Contingency Construction Doctrine

A base camp can contain one or more units from or more services, and support U.S. and multinational forces and interorganizational partners, requiring a large enough perimeter to house on a large enough area (DA, 2017). The *Base Camps* doctrine attempts to prevent inconsistent base camp implementation because in the end they are generally classified by their size, level of service, and purpose, despite their service component or their commands (DA, 2017, p. 3-2). Ad hoc infrastructure that evolves without the essential planning, integrate construction practices, and protective measures tends to exhibit deficiencies and waste limited resources, poses risk to inhabitants and the environment, and results in a weakened overall mission. The consequences when base camp activities become detrimental to commanders, that should always be considered when planning for housing operations, are as follows (DA, 2017, p. 4-1–4-3):

- Limited and inefficient use of resources, such as time, materials, water, energy, fuel, and money
- Hazardous dangers, like fire and electrocution, linked to improper building
- Personal health issues linked to trash burning or inadequate waste management
- Residual environmental issues, such as air pollution, contamination of groundwater, or loss of protective coverage

Base Camps (DA, 2017) states when choosing an initial site, it naturally falls into development, the temporary site must be considered because it almost always becomes the de facto base camp (p. v). Also, base camps are resource-intensive which requires the level of effort, despite labor, equipment, and materials required, the amount and type of resources exhausted, and the scale of technical and engineering skill needed to determine the size of base camp AO (DA, 2017, p. 1-1). Furthermore, construction standards that can determine the minimum capability when choosing housing type based off deployment duration (DA, 2017).

DoD Directive 3000.10 *Contingency Basing Outside the United States* (DoD, 2021) discusses multinational and joint standardization/operations for world-wide bases to ensure common standards across all branches. It instructs what contingency housing type benefits the mission, acquisition leaders must consider sustainment burden, maintenance and operational energy, environmental impact, deconstruction/closure base requirements (p. 5-6) and total equipment life cycle. It is important to note this publication does stress the DoD objective in basing outside of the US is to be efficient and reduce of logistics burden as much as possible, such as reducing fuel and water demands, minimizing logistical footprint, modular, scalable construction, and improving energy efficiency (DoD, 2021, p. 3-4).

The UFC is the DoD standard practice that establishes standardization requirements for the layout, construction, and facility performance for military structures worldwide (DoD, 2021, p. 8). It guides survivability, durability, habitability, and life cycle standards used in this study to continue to evaluate contingency housing systems.

These resources are important for this research because they evaluate contingency basing, helping define military requirements for shelter duration, habitability, and protection. The doctrines set standard conditions when evaluating survivability, logistics, and sustainability. Also, it explains the duration baseline definition for temporary vs. semi-permanent infrastructure, and therefore matching shelter systems to the AO's environment, duration, and mission circumstances (DA, 2017).

B. ADDITIVE MANUFACTURING CAPABAILITIES AND MATERIALS

Construction 3D printing is a highly customizable, free-form, new tech with the ability to disrupt the traditional construction market with the potential of mass-producing military housing. According to Grand View Research (2023), the industry is projected to increase at an annual rate of 23.9% over the next decade (para. 1). This growth opens the door for experimental projects, prototype into move-in-ready, affordable housing solutions (Becher, 2024). As the popularity in the AC technological research and development increases, because it will lower the cost of the technology resulting in several economic phenomenons: economies of scale, learning curve, and technological deflation. This is an important notion for military acquisition to which it allows the cost of equipment decreased, making them affordable. An important factor to consider when it comes to source selection and procurement, giving the military a reason to increase their purchase more equipment. Another extremely important factor for the military to minimize transportation material supply chain footprint. Also, AM can be sustainable, low-waste, including biodegradable and material alternatives under development (Becher, 2024). In the same article, *12 Examples of 3D-Printed Houses* (Becher, 2024), it states 3D-printed house developers have reported cost savings of up to 30 percent. ICON, a 3D-printing construction company the Army has been working alongside, declares it can create a 600–800 square foot, economy-sized building for as low as $4,000 in 24 hours (Becher, 2024; ICON, n.d.). Becher (2024) discusses another technological advancement from the University of Maine is in 3D materials for housing structures is creating them from bio-resin and wood fibers to combat labor shortages and extend inexpensive housing options (para. 14). Creating a 600 square foot prototype, a one-bedroom and one-bathroom building made entirely of 100% biodegradable materials, including its wood floor (Becher, 2024). Becher (2024) also claims designers construct 3D-printing concrete holds comprehensive strength three times greater than conventional brick material with companies capable of performing at twice the speed of traditional construction, resist against natural disasters such as tornadoes and fires, and prevent from termites (para. 14).

C. LIMITATIONS OF TRADITIONAL SOLUTIONS

1. Survivability Issues

TEMPER tents have several limitations in austere environments. The "vinyl coated polyester duck cloth" pliable walls are vulnerable to extreme weather, therefore survivability may score poorly and provides minimal protection to warfighters (Defense Logistics Agency [DLA], n.d.).

According to SteelMaster (n.d.a), barracks huts (B-Huts) are made of steel that are presumed to cause issues with insulation. There are two model types, Nissen and Quonset huts, and they have ranged in size throughout the decades, initially making their debut during World War I (SteelMaster Buildings, n.d.a). They are open-bay style which can be good for camaraderie but does not provide much privacy. However, for survivability it can prove itself a good choice because they are made of corrugated galvanized steel, which is a great option for survivability for warfighters (AgriBilt Building Systems, n.d.). Also, they may lend themselves difficult for logistical efficiency because they are not organic to military units and must be contracted out from third-party private companies.

CLUs (Container Living Units) are repurposed shipping containers made into small living quarters for warfighters overseas. Prefabex (n.d.) explains one of their many benefits is their structure strength offering good survivability by offering durable structure and weather resistance. Shipping containers are made of corten steel, a high-strength material (Eagle Leasing Company, n.d.). However, they are logistically demanding since they require to ship in one-piece and use heavy machinery to be moved around AO.

2. Logistics and Supply Chain Constraints

Tent Extendable Modular Personnel (TEMPER) tent is a adaptable, very portable for a broad range of environments with the capability to quickly modify it into different configurations. Also, due to its versatility this tent can be used for more than just housing quarters in deployed environments. According to the National Museum of the US Air Force (n.d.), TEMPER tents have an aluminum frame, and as stated before its reinforcement material is vinyl cloth that is fire, mildew and water resistant, to include the capacity for heating and air conditioning.

B-Huts design was to provide quick and effective shelter resolution during wartime, however they have logistical limitations because although they are prefabricated, they still require material transport and assembly resulting in longer construction process (SteelMaster Buildings, n.d.b). B-Huts have a similar configuration capability to tents, and they come in several sizes depending on the contractor/builder the military organization decides to acquire them. However, there structures are designed for fast construction with a small crew, even Soldiers assisting in the process (SteelMaster Buildings, n.d.b).

CLUs, also known as Containerized Housing Units (CHUs), are logistically different than the other two options because it must be moved as a complete unit by cranes, forklifts, or Enhanced Containers Handling Unit (ECHU). Then on arrival it does require experienced technicians for assembly of the living quarters. Luckily, when the CLUs arrive at the base camp, or operational zone, as stated by Prefabex (n.d.), it allows for modularity by stacking or combining units (para. 7).

D. CURRENT READINESS AND AM STRATEGY

1. Housing Types in Research

For basic understanding of the housing types, or living quarters, discussed in my study, the following types are important to briefly define for comparison:

- **TEMPER Tents**: Soft-sided shelters used for troop billeting, command posts, and medical stations. They are modular, air-beam or aluminum-frame supported, and designed for quick setup and mobility (National Museum of the US Air Force, n.d.).
- **CLU**: Steel International Organization for Standardization (ISO) container–based housing converted for troop accommodation. They can be stacked on top of each other and have integrated HVAC and electrical within the unit (Prefabex, n.d.).
- **B-Huts**: Metal structures that offer insulation potential (SteelMaster Buildings, n.d.a), and based off personal experience, has the capability to offer room partitions.
- **AM**: Concrete structures produced using large-scale 3D-printing systems (Becher, 2024).

2. Technology Readiness

The *Automated Construction of Expeditionary Structures (ACES)* initiative, developed by the Army Corps ERDC-CERL team, focuses on researching DoD's effort to advance AM technologies for field application (Al-Chaar et al., 2021, p. ii; ERDC, n.d.). The ACES research focuses on designing and constructing more sustainable structures capable of supporting forward deployed warfighters. Its objective is to reduce material, labor, and resource requirements to build and deploy operating infrastructure (Al-Chaar et al., 2021, p. ii). The project was take on to develop the ability to "print" rapid structures on demand, in the field, using local materials with a minimal number of personnel (Al-Chaar et al., 2021; Rushing et al., 2017). ERDC utilized AM to perform construction using locally available materials with minimum number of personnel. One of the materials they are continuing to experiment with is non-conventional concrete, that can offer a huge benefit by reducing waste, lower expense, and speed up development (Al-Chaar et al., 2021; Rushing et al., 2017).

a. Concrete

Currently, traditional MILCON (military construction) utilizes traditional concrete material, which is limited in comparison to AM (Al-Chaar et al., 2021). In ACES experiment, a conventional concrete mixture relies on standard Portland cement, natural aggregates, minimal admixtures, alongside conventional mixing techniques (Rushing et al., 2017). The mixture was tested for flow, setting time, and early compressive strength (Al-Chaar et al., 2021).

b. Current Dwell Time in Forward Mobilizations

In 2012, the Army announced deployments will be nine months long to ensure good work-life balance (McIlvane, 2011). Active military component began nine-month deployments, versus the 15-months at the height of the Afghanistan and Iraqi war during the early 2000s, to provide stability for service members at home station. However, Reserve component when activated, although at a lower rate than active component, does spend more time activated due to their required 3-month premobilization prior to starting their deployment rotation. Currently, the Fort Bliss barracks project is to lodge Reserve component soldiers in support of their premobilization while training in an austere environment to ensure the unit is prepared for their deployment (Poe, 2025). So, in a Reserve Component they can spend 12-months activated, which includes the 3-month premobilization and 9-month deployment. This information is important to understand the timeframe a warfighter is spending in an austere environment. It helps acquisition professionals plan and prepare for equipment maintenance and logistical demands.

c. Industry Partnerships in Construction Additive Manufacturing

ICON, a technology and construction 3D-printing company based out of Texas devoted to addressing the housing crisis by delivering high-quality homes faster and more affordability (ICON, n.d.). ICON has worked jointly with DoD to deliver numerous projects that go beyond residential construction. ICON has helped build a 5,700 square foot, energy-efficient barracks building that can house up to 56 soldiers per building, housing personnel in a controlled environment to temporarily home National Guard and U.S. Army Reserve rotational units to prepare for deployment rotations (Poe, 2025). It utilized an automated construction-scale technology and improved materials to deliver military barracks at faster speeds in comparison to traditional construction (Defense Innovation Unit [DIU], 2022). Its goal is to restore temporary barracks and structures that have surpassed their lifespan with modern structures to reduce overall life cycle costs (Bauguess, 2022). They continue to remain innovative by exploring the mixture of traditional construction finishes and integration of troop labor of the Fort Bliss barracks, like in the build of Camp Mabry Innovation Center in Austin, Texas (Bauguess, 2024).

ERDC, a research and development center for the U.S. Army Corps of Engineers. They support, develop, and deliver advanced solutions to the nation's current challenges in military matters (ERDC, n.d.). As the military continues to research with AM, it utilizes ERDC's CERL to aid research and develop 3D construction. Recently they aided the procurement of the Fort Bliss project barracks to oversee the compliance of the project in accordance with UFC alongside ICON (Burman, 2025). Their innovation helps develop criteria and provide direction in preparation for the construction in expeditious environments.

3. Comparative Case Studies

a. Fort Bliss Barracks Project

There is currently no forward deployed 3D construction AM project in practice, however there are projects in austere areas that mimic deployment environments. Notable field projects, as discussed in this research multiple times, include the construction of two 3D concrete printed structures located at Camp Pendelton and Fort Bliss (Bauguess, 2020; Poe, 2025). ICON and ERDC, along with contracting subject matter experts (SMEs), created a lodging pilot program whose goal is to provide housing for premobilization Reserve component units in preparation for deployment (Espinosa, 2025; Poe, 2025).

b. NATO Living Quarters

In support of the North Atlantic Treaty Organization (NATO)'s and its operational missions, 32 members nations collectively work together to sustain a complex and versatile operating environment (NATO, n.d.). NATO missions often require hundreds of government officials, civilians, and military personnel to reside in temporary or semi-permanent dwellings located in displaced or austere areas (NATO, n.d.). NATO commonly employs the three conventional housing types (Tents, CLUs, and B-Huts). In addition to other shelter system modifications they use are:

- **Hard-walled prefabricated modular barracks**, which are like CLUs but are different from these structures because they have panel-built hard-walls, rather than those made of ISO containers (Prefabex, n.d.).
- **ISO containerized expandable shelters**, also like CLUs, but have expandable walls which are used for multiple purposes, such as field hospitals and mobile offices. These assets also exist in military units, approved by DoD however they are utilized as tactical shelters, they are limited and only used for logistical support (MilShel, n.d.).
- **Host Nations (HNs) infrastructure and security forces** if alliances allow it and can provide functions to support U.S. forces (DLA, n.d.; DA, 2017).
- **Combat Army Modular System Shelter (CAMSS)**, a combination of Quonset style B-Huts and TEMPER Tents but are made of soft-walled fabric. Utilizing tents is not an innovative approach, but AOT International is continuing to research advanced tent shelter systems (AOT International, n.d.).

While these systems are effective for short-term deployments, they are not considered innovative or enduring solutions. However, according to American Military News (2025), NATO continues to research and assess advanced shelter technologies, including AM (3D printing), to improve sustainability, habitability, and mission readiness to support their complex missions (American Military News, 2025).

4. Gaps in Current Research

Existing research on expeditionary housing within the military remains limited, emphasizing structural performance and logistical efficiency while overlooking the human factor with 3D-printed construction. There is also a lack of cross-system comparisons evaluating AM against traditional housing options such as TEMPER tents, CLUs, and B-Huts. Also, few studies explore how integrating new construction technologies affects soldier welfare and overall readiness. Acquisition professionals make infrastructure decisions based on current threats, challenges, timelines, and mission requirements. These decisions can only be better informed if we research cross-system performance alongside soldier welfare data to help planners with measuring advantages in traditional versus new systems.

III. METHODOLOGY

This study uses a qualitative comparative analysis (QCA) paired with a multi-criteria decision analysis (MCDA) model (Keeney & Raiffa, 1993) to evaluate additive manufacturing (AM) housing options, in comparison to conventional housing options. QCA enables systematic comparison across heterogenous systems, while MCDA provides weighted, criterion-based scoring grounded in operational relevance. The analysis integrates military doctrine construction, government research and development (R&D) reports, case studies, and a subject matter expert (SME) survey to assess performance across four dimensions:

- Structural Survivability
- Logistical Footprint
- Equipment Lifespan
- Habitable Adequacy

This method design allows the study to produce an evidence-based evaluation of AM feasibility in austere environments.

A. RESEARCH DESIGN

The MCDA scoring framework draws from SME insights, documented performance data, and doctrinal analysis. A 16-participant voluntary survey was conducted, that consists of military personnel in defense in connection with the Naval Postgraduate School (NPS), used for this research to capture specialist perspectives on the comparative important and operational relevance of each criterion. Participants represented five U.S. branches and various functional backgrounds, ensuring a balanced mix of operational and non-operational experience.

Survey participants rated the importance and acceptability of trade-offs across the four performance dimensions using a standardized scale aligned with the MCDA model. These inputs informed the weighting structure, while secondary data and literature established the baseline scoring for each housing type. The combined methodology ensures the results represent both practitioner judgment and empirical evidence.

The research design aims to produce a decision-relevant assessment that can inform future Army and DoD infrastructure planning and modernization efforts.

a. Survey Scenario and Instrument Design

In attempt to validate the MCDA framework, conducted a voluntary survey format with two scenarios, which were utilized to replicate a realistic scenario to determine the best answer based off participants' professional opinion. Participants were asked to evaluate how each of the four housing types satisfies the four primary assessment dimensions under the scenarios' operational context and environmental stressors. This confirms that responses reflect abstract preferences, as well as mission-specific trade-offs, to ensure various opinions of operational application in the weighing and scoring data.

The scenarios present participants with fictious but conceivable scenarios, such as contingency basing in austere early-entry operations, medium-duration stability missions, and a semi-permanent FOBs. The scenarios are developed to align with existing joint contingency basing doctrine and conventional options. It ensures respondents engaged with the evaluation criteria from real-world military decision-making.

B. MEASURES OF EFFECTIVENESS FRAMEWORK

The measure of effectiveness (MOEs) framework for each housing type against relevant expeditionary operations. The basis is grounded in DoD standards for contingency basing, survivability, habitability, and logistical efficiency. This structure ensures a comprehensive evaluation aligned with real-world operational requirements. Figure 1 demonstrates this study's framework to investigate the best pathway to research the housing types under a comparable, realistic setting.

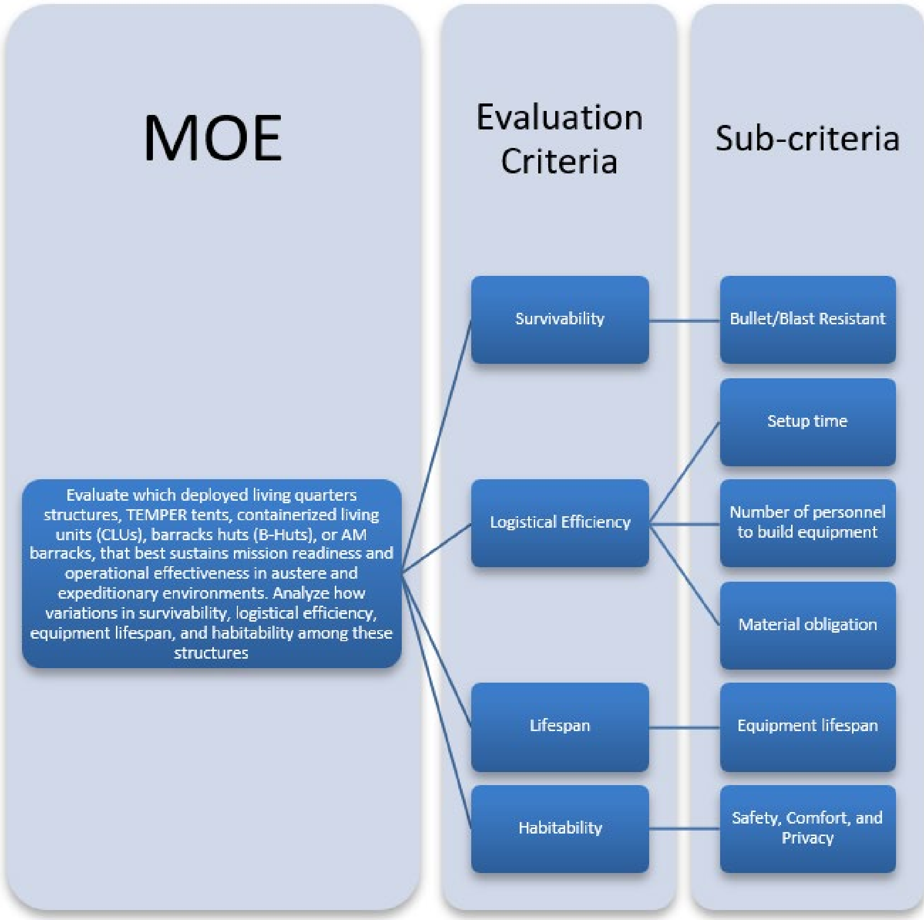

Figure 1. Measures of Effectiveness Hierarchy

C. ANALYTICAL FRAMEWORK

The analytical framework applies to the MCDA method to systematically evaluate and compare the four housing systems. MCDA is particularly well-suited for problems requiring the balancing of competing operational factors. Each criterion is defined using measurable sub-metrics drawn from doctrine, engineering literature, and SME input.

1. **Structural Durability:** Resistance to environmental, operational, and ballistic stresses.

2. **Logistical Efficiency:** Reduction in supply chain demands, manpower requirements, and transportation footprint.

3. **Equipment Lifespan:** Time a piece of equipment setup for soldier readiness.

4. **Habitability Adequacy:** Suitable to safely, comfortably, and privately live in limited resource and constraint housing conditions.

All four criteria are initially weighted equally for baseline comparison, sensitivity analysis evaluates how results shift when survivability and logistics, identified as the two highest-priority criteria, receive greater weight. Scores assigned to each housing system derive from validated performance data, supported by SME inputs where available.

The MCDA outputs are displayed in comparative tables and charts to communicate differences across systems clearly and support prioritization.

D. CRITERION

For the housing system, a performance score is assigned from 1 (low) to 3 (high) for every criterion, reflecting relative effectiveness based on available data and SME input, see Table 1. These scores were then multiplied by the criterion weights to generate the final MCDA results. This scoring method enables consistent comparison among structurally different systems.

Table 1. Scoring Scale

Scoring Scale		
Score	Performance	Definition
3	High	Exceeds performance of baseline structure; strong operational or cost advantage
2	Moderate	Performs at baseline in most metrics, feasible and advantageous in limited conditions
1	Low	Marginal improvement or comparable to baseline; benefits do not outweigh logistical or cost burden. Possibly does not meet baseline standards.

1. Survivability

Survivability measures the structural resilience of each housing system under environmental and operational stresses (such as extreme temperatures, wind, and precipitation) and operational hazards (such as projectile impact). The evaluation incorporates unguided, rocket-propelled projectiles (RPGs) hazards as a baseline threat common across operational environments (Loewner, J., & Miller, E., 2023). Survivability (S-index) are evaluated via a weighted hierarchy (O'Laughlin, 2023, March 21). The metric chart, see Table 2, shows the weight within the category, which is the total **unweighted score of survivability** adding up to **100%**.

Table 2. Survivability Metric Chart

Category	Sub-Metric	Definition/Focus	Weight within Category
Survivability (60%)	Blast Resistance	Resistance to overpressure and structural failure during explosive events	25%
	Debris/Impact Resistance	Ability to resist penetration or breach from fragments, wind-borne debris, or small arms impacts	20%
	Fire Resistance	Resistance to ignition, flame spread, and structural compromise during fire exposure	15%
Durability (40%)	Wind/Serviceability	Capability to maintain stability and livability under high wind loads and storm events	20%
	Environmental Degradation	Long-term resistance to corrosion, mold exposure, moisture intrusion	20%

2. Logistical Footprint

Logistics assesses the total resources required to build, transport, and sustain each housing system, including equipment volume, weight, manpower, and resupply burden. A small logistical footprint correlates with fewer vulnerabilities and reduced strain on transportation assets. A smaller logistical footprint reduces supply chain vulnerability and releases transportation needs for other mission-critical items. The metric chart, see Table 3, shows the weight within the category, which is the total **unweighted score of logistics efficiency** adding up to **100%**.

Table 3. Logistics Metric Chart

Category	Sub-Metric	Definition/Focus	Weight within Category
Construction & Sustainment Efficiency (60%)	Manpower Requirements	Labor hours required for construction, setup, and teardown	25%
	Equipment Requirements	Quantity and complexity of construction equipment or printers, including power and water needs.	20%
	Resupply & Maintenance Frequency	Resupply frequency of building or set up materials (like, fuel, spare parts, consumables), maintenance burden during operations	15%
Deployment & Transport Requirements (40%)	Material Volume & Weight	Total mass and cubic volume of materials required for construction	20%
	Transport & Mobility Demand	Number and type of transport assets (like, C-17, HEMTT,etc.) needed to deploy a standard 512 ft² unit	20%

3. Equipment Lifespan

Equipment lifespan evaluates both the reliability of construction systems and the longevity of the housing structures themselves. Sub-metrics include mean time between failures, maintenance frequency, component replacement intervals, and environmental robustness. Service Longevity will measure service life and environmental robustness to focus equipment degradation. The metric chart, see Table 4, shows the weight within the category, which is the total **unweighted score of equipment lifespan** adding up to **100%**.

Table 4. Equipment Metric Chart

Category	Sub-Metric	Definition/Focus	Weight within Category
Operational Reliability (60%)	Mean Time Between Failures (MTBF)	Average operating hours or cycles between mechanical or system failures requiring repair	25%
	Maintenance Frequency & Downtime	Frequency and duration of preventive or corrective maintenance during normal operation	20%
	Component Replacement Interval	Expected interval before major components (like, printer parts, generators) require replacement	15%
Service Longevity (40%)	Total Service Life	Expected years or cycles of functional use before complete overhaul or decommissioning	25%
	Environmental Robustness	Resistance of equipment to degradation from dust, temperature extremes, moisture, and handling during transport	15%

4. Habitability

Habitability examines whether a system can support soldier quality of life (QOL), to essentially make the inhabitant's life comfortable during the duration in the austere environment. A living space that is a good fit for human occupancy to render comfort and basic amenities. Sub-metrics include safety, privacy, environmental control, sanitation access, and thermal comfort. The metric chart, see Table 5, shows the weight within the category, which is the total **unweighted score of habitability** adding up to **100%**.

Table 5. Habitability Metric Chart

Category	Sub-Metric	Definition/Focus	Weight within Category
Physical Environment (60%)	Thermal Comfort & Environmental Control	Ability to maintain temperature and air quality within acceptable ranges. Includes HVAC performance, insulation, &ventilation	25%
[redacted]	Noise & Light Layout	Capacity to mitigate exterior noise. Control lighting for proper living condition	20%
	Interior Space & Layout	Expected interval before major components (like, printer parts, generators) require replacement	15%
Psychological & Health Factors (40%)	Privacy & Personalization	Degree of privacy and individual space allowing rest, and proper separation from work and personal space	20%
[redacted]	Hygiene & Sanitation Integration	Accessible wash areas, restrooms, and cleaning facilities. Control of mold, odor, and humidity	20%

E. LIMITATIONS OF THE METHODOLOGY

This study has several methodological limitations:

- Thesis does not support an in-house trial or in-exercise testing. Technology rapid maturity does not guarantee updated information, therefore causes limiting generalizability.
- Data is limited to unclassified, open-source data. The assumption of available required resources, such as power, water, and secure staging areas, for modular construction is being conducted in a deployment zone.

- SME participation is used selectively, not as a statistically representative sample.

Delimitations include the focus on company- or platoon-sized housing. Evaluations are limited to large-scale 3D concrete printing, and an operational timeframe of 5–10 years.

F. DATA SOURCES

The study relies on secondary data obtained from four main categories:

1. **Military Doctrine and Technical Standards:** Official U.S. Army and DoD publications that define requirements for contingency construction, such as *Base Camps* and *Unified Facilities Criteria* (UFC) regulation/doctrine.

2. **Government Research and Development Reports:** Publications from the Army Engineer Research and Development Center (ERDC) and Marine Corps Systems Command AM demonstrations, including the Automated Construction of Expeditionary Structures (ACES) program.

3. **Industry Case Studies:** Open-source reports and press releases from companies like ICON that have partnered with military or government agencies to build 3D-printed structures.

4. **Peer Reviewed Academic Literature:** Engineering and construction management research articles covering AM performance, material science, and structural design relevant to modular shelter construction.

Relevant documents were identified through targeted searches of official military, DoD, and Army Corps of Engineers digital libraries, academic databases, military publication websites, and reputable industry publications. Search terms included combinations of military AM, 3D concrete printing, modular barracks, contingency construction, forward operating bases, and UFC.

Two measures for data collected:

1. **Relevancy:** Documents and publications reviewed to ensure they addressed one or more of the evaluation criteria (structural durability, construction speed, cost-effectiveness, logistical efficiency, or environmental adaptability) and were specific to military or expeditionary construction background.

2. **Quality:** Sources are based on credibility, date of publication (material from the last 10 years), and the presence of verifiable performance data.

There are multiple sources cross-referenced to confirm data accuracy. Summaries, performance metrics, and relevant quotations were extracted into a structured analysis matrix to support the MCDA framework. This process ensures transparency and consistency in how the evidence is gathered and evaluated.

G. SUMMARY

The methodology provides a structured, defensible approach for evaluating the feasibility of AM barracks in contingency environments. By combining MCDA, QCA, doctrinal analysis, and SME inputs, the framework ensures that findings reflect both operational realities and technical considerations. This foundation supports the analysis the next chapter in the recommendations section.

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IV. FINDINGS AND COMPARATIVE ANALYSIS

The findings and comparative analysis in this thesis incorporate results from a peer subject matter expert (SME) survey used alongside the researcher's perspective. The survey represented five U.S. service branches, the Air Force, Army, Marines, Navy, and Coast Guard, who possess 0 to 16+ of professional experience. Their backgrounds vary in contracting, engineering, logistics, operations, aviation, and investigations, providing diverse perspectives. Notably, 43.8% of respondents have direct experience in supporting contingency basing or deployed infrastructure, while 56.3% had no prior contingency basing experience, creating a nearly balanced participant SME knowledge, which yields a valuable mix of functional and non-functional experience. The representation from this survey provides a conservative representation of the broader military population, of course, recognizing each branch's distinct mission set that makes its operational exposure unique from one another. Annotating this characteristic is important because these individuals represent the acquisition workforce and future decision-makers. Many of these personnel may one day work on contingency basing or deployment infrastructure who benefit from understanding the warfighter's perspectives, as to make the best, most effective decision. Nonetheless, the diversity of the participants backgrounds and different experience levels help interpret the comparative performance of the four housing systems, which allows multiple insights within the multi-criteria decision analysis (MCDA) framework, all valuing different things but maintaining the most important standpoint: identifying which housing system best supports soldier readiness, safety, comfortability, and operational effectiveness.

A. SECONDARY DATA RESEARCH

1. Structure and Survivability Feasibility

Analysis from ERDC reports and AM case studies shows that 3D-printed structures demonstrate significantly higher compressive strength compared to conventional structures, along with fire resistance and environmental durability (Al-Chaar et al., 2021; Becher, 2024). Containerized living units (CLUs) do not inherently offer inherent blast and ballistic protection regardless of their steel exterior walls (OASIS Engineering, n.d.), a feature SMEs were not widely aware of prior to the survey. Tent Extendable Modular Personnel (TEMPER) tents remain the least survivable option due to their fabric walls.

The dependency of mission duration can determine the life span of a base camp which helps determine the housing type to choose from. Therefore, designing base camp AO based on reasonable assumptions, but if wrong, can result in wasted construction or inadequate facilities and infrastructure (DA, 2017).

2. Habitability and Soldier Welfare Feasibility

Habitability considerations, privacy, environmental control, sanitation, and comfort, were consistently ranked as high priorities by SMEs. AM structures and CLUs both scored highest in this area due to their exterior properties, configurable interior layouts, and ability to support HVAC systems. TEMPER tents scored lowest due to limited environmental control, low privacy, and susceptibility to weather. Barracks huts (B-Huts) performed moderately, delivering better comfort than tents but lacking durability and environmental control compared to CLUs or AM (Gordian, 2024; GAO, 2023).

To further examine habitability and soldier welfare, at base camps are to provide livability resources (DA, 2017). There are field services, personnel services, and life support-related activities to improve quality of life (QOL) and effectiveness for occupants at base camps. To include a few other services, such as waste management, sewage treatment, dining, medical, laundry, financial, legal, religion, postal, Morale, welfare, and recreation (MWR) activities, and base exchanges (DA, 2017). Of course, the initial phase of a base may not supply all this immediately, it will eventually warrant a need to provide these services based off the base camp level of support proposal (DA, 2017). Which means the government employees and civilians that work in these areas require living quarters. Therefore, commanders must keep this as a planning consideration when deciding on AOs.

3. Trade-Offs Discussion

In acquisition source selection, a common practice is balancing competing factors when choosing systems to procure. In this case, we have very different systems which require evaluation of performance characteristics in two different settings, forest/low plains and desert environments. SMEs responded similarly, despite the two different scenarios. These priorities produced clear trade-offs among the four housing systems:

- **Tents** offer unmatched mobility and low sustainment burden but perform poorly in protection and long-term habitability.
- **B-Huts** provide moderate comfort and space but lack survivability and require external labor, limiting their ease of logistics efficiency.
- **CLUs** deliver the strongest overall balance, good protection, reliable environmental control, and strong habitability, though they require moderate deployment effort and are not inherently ballistic- or blast-protected despite common assumptions.
- **AM** preformed well overall, right behind CLUs. However the results demonstrated variations in participant responses, giving the impression that SMEs understand the developing technology's capabilities but lack familiarity to properly evaluate it.

Collectively, these findings reinforce that **no single housing system excels in every criterion**; instead, each key trade-off lies between **maximum survivability** and **acceptable logistical burden** to choose the correct option. The results highlight the importance of selecting housing based on mission duration, environmental conditions, and available logistical capacity, rather than expecting one universal solution. Even though soldiers often adapt their spaces creatively for comfort, the fundamental trade-offs identified by SMEs suggest that protection and readiness must remain at the forefront of contingency housing decisions. While we are not relying on soldier adaptability and creativity in this research, it is important to note that just like the TikTok influencer mentioned in the introduction of this study (Taylor, 2024), people are naturally innovative and have been known to make their creature comforts upon settling into a living space.

4. Effects of Force Structure

Force structures affect not only deployment timelines but also sustainment requirements. AM construction requires power generation, a protected build site, engineer support, and printer maintenance (McBirney & Burton, 2022). TEMPER tents are soft-walled living quarters (National Museum of the U.S. Air Force., n.d.), which do not protect from any adversary threats or dangerous weaponry. Hence, the reason that tents scored so poorly in the MCDA summary. B-Huts are great structures for natural disasters, such as tornadoes, hurricanes, snow, and are fire-resistant with Quonsets design (SteelMaster, n.d.b). There is limited information on blast resistance on B-Huts, however there is a Navy manual that documented information on B-Hut, Quonset model. It states B-Huts have good protection from bomb blast, while it does not specify on the blast resistance details (Navy, n.d.). The manual states "men in bunks are thereby protected against the effect of bursts at a distance but not against direct hits or near misses" (Navy, n.d, p. 2). Also, to strengthen the B-Huts construction, personnel can construct surrounding protective structures, such as a wall, embankment, or placing the entrance below ground level (Navy, n.d.).

Another unforeseen research insight found in this study was the lack of blast resistance for standard military ISO CLUs. Their walls are 14-gauge steel (~1.6mm thick), but are not designed to stop bullets, shrapnel, or blast-proof, but experts can engineer modify them upon ordering them such requirements (OASIS Engineering, n.d.). Those special ordered units can absorb shock waves to mitigate explosions as best as possible and reinforce the structure by adding blast-resistant materials to offer more protection (OASIS Engineering, n.d.).

AM is a developing technology, with a lot of potential for initial operational test and evaluation (IOT&E) on it. In August 2018, Army Corps Engineer Research and Development Center (ERDC) conducted an experiment on an AM B-Hut shaped model with 85% of the walls printed in 40 hours, which had ballistic and blast testing (Technology Experimentation Center, 2023). A .50 caliber M33 ball round projectile did not penetrate the target, AM B-Hut, primarily attributed to a mild-steel core. However, the test was done again with a .50 caliber APM2 projectile with a hardened steel penetrator but was not successful, it resulted in complete penetration. There was detonation test on the structure walls, with third test resulting in a hairline crack of the knife edge with gauge mounts (Technology Experimentation Center, 2023). In the same experiment, they discovered AM can be logistically efficiency during its initial phase if there is an ability to extract construction material from the local natural environment (Technology Experimentation Center, 2023). Overall, a acceptable and durable result that is presumed to be safe for warfighters.

B. SURVEY FINDINGS

Survey results provided initial insight into how SMEs rated each housing system across survivability, logistical footprint, equipment lifespan, and habitability. SMEs consistently rank CLUs and AM structures as the strongest options, particularly for missions requiring extended duration or higher levels of protection. TEMPER tents were preferred only for short-term, high-mobility missions, while B-Huts scored moderately but did not emerge as the preferred choice under either climate scenario. The study does include detail information on all participant responses for both operational scenarios.

For forest and low plains environment in humid, semi-arid climate (modeled after Venezuelan lowlands or northern Colombia), survey participants responded, in order of questions. Rank survivability, logistical efficiency, equipment lifespan, and habitability:

1. Service members consistently emphasized the most important contributors to successful deployed soldier housing are survivability and habitability, see Figure 2, followed by logistical footprint and equipment lifespan. Respondents prioritized structures that protect soldiers and equipment from environmental and dangerous threats while providing acceptable living conditions, particularly environmental control, sanitation, privacy, and protection from mold or weather. All respondents focused on force protection and quality of life which outweighed lifespan maintenance considerations. When forced to make trade-offs under resource constraints, survey participants were clear that survivability is non-negotiable. The first criterion they were willing to compromise was logistical efficiency, accepting slower setup, greater manpower

requirements, or higher transport costs if it ensured safer and more livable conditions. Equipment, lifespan and habitability where also areas respondents were more willing to trade, but safety remained the highest priority.

2. Across overall performance in humid and jungle environments, CLUs emerged as the top-rated housing type, with AM structures scoring only slightly lower, reflecting strong confidence in their structural durability and environmental resilience. B-Huts were viewed as adequate but not ideal, and tents were consistently rated the poorest performer due to their limited protection, low durability in humidity, and weak environmental resistance. Respondents also viewed CLUs and AM structures as the most sustainable options, see Figure 3, with B-Huts trailing slightly behind and tents considered the least suitable for long-term use in wet or tropical climates.

3. In terms of deployment ease, tents were rated as the easiest to deploy, with B-Huts viewed as moderately difficult and CLUs as more challenging. AM structures were perceived as the most logistically demanding due to their equipment, material, and power requirements. Regarding protection and structural resiliency, tents again performed weakest, with B-Huts considered moderately protective. CLUs scored highest in structural resilience, closely followed by AM structures.

4. For logistical load, respondents rated tents as the least demanding, while B-Huts and CLUs were seen as moderately challenging. AM structures were viewed as the most maintenance-intensive, reflecting unfamiliarity with the technology and assumptions about equipment upkeep. Finally, when evaluating comfort and habitability, AM structures were rated highest, followed closely by CLUs. B-Huts offered moderate comfort, and tents received the lowest ratings across all respondents.

5. Surveyors were asked how confident they are that AM will be operationally viable in the next 5 years (operating outside of a controlled environment) in forest/low plains, humid-arid conditions. 25% of service members are very confident and 18.8% somewhat confident, 18.8% are neutral, 31.3% are uncertain, while 6.3% are not confident. A quarter of respondents are 43.8% confident in a lean positive viewpoint. A small neutral population suggesting that available information does not yet provide a clear trend if AM can operate in a humid, semi-arid environment. Nearly one-third of participants are uncertain, indicating many views AM as promising but not predictable housing choice. 6.3% state they were not confident in this technology's development in the next 5 years.

6. The biggest barriers the service members see with 3D-printing housing technology in contingency operations are providing power and water requirements to the structure and its location is very important due to these logistical constraints, equipment transportability scored the second hardest barrier as a major concern when moving it in austere terrain. The training and technical skills are seen as a moderate barrier, although not critical but significant. While policy or acquisition barrier is viewed as the smallest obstacle. Surveyors identified power and water requirements followed by equipment transportability as the biggest barriers to fielding 3D-printed structures in contingency operations.

7. The survey participants were asked if they had to choose one housing type for future expeditionary operations, which would they select and why. M B-Huts, again, had sufficient support, with individuals who valued personal space, modest habitability, and traditional semi-permanent shelter familiarity. participants were asked if they had to choose one housing type for future expeditionary operations, which would they select and why. Most responses revolved around the length of the mission durations, with

choosing tents for initial, short-term/rapid entry and CLUs or AM structure for longer-term or enduring operations.

For desert environment in hot-arid, low moisture climate (modeled after Kuwait, Northern Saudi Arabia, or Southern Afghanistan), survey participants responded, in order of questions. Rank survivability, logistical efficiency, equipment lifespan, and habitability:

1. Service members again identified survivability and habitability as the two most critical criteria for successful deployed housing in hot-arid climates, see Figure 2. Protecting soldiers from lack of natural cover, exposure to extreme heat, and environmental or dangerous threats ranked as the highest priority. Logistical footprint was considered moderately important, primarily due to the burden of transporting water and fuel, cooling systems, and hygiene facilities required for environmental control. Equipment lifespan ranked lowest, as respondents viewed immediate survivability and logistical footprint as far more decisive to mission success.

2. When faced with constrained resources, respondents remained consistent with the forest scenario: survivability was the least negotiable criterion, followed by habitability due to extreme heat risks. Respondents were more willing to accept trade-offs in equipment lifespan and logistical efficiency, viewing both as secondary to ensure soldier safety and reduce heat stress.

3. In terms of overall performance, CLUs again ranked as the best housing option, see Figure 3, followed closely by additive manufacturing (AM) structures, which received strong support despite their emerging nature. B-Huts were viewed as moderate performers, while tents scored the lowest due to insufficient protection from heat, dust, and environmental hazards. CLUs and AM structures were also seen as the most sustainable in hot, arid environments, with B-Huts showing mixed but generally moderate ratings. Tents were consistently identified as the least sustainable and least

durable, particularly under harsh sun exposure, high winds, and sand abrasion.

4. Regarding ease of deployment, survey participants again rated TEMPER tents as easiest to set up, with B-Huts and CLUs viewed as moderately difficult. AM structures were considered the most difficult to deploy due to their significant equipment, material, and power requirements. This scenario was notable because B-Huts and CLUs received identical ease-of-deployment rankings, the only scenario where two housing types tied.

5. For protection and structural resiliency, tents continued to score the lowest. B-Huts and CLUs provided moderate resiliency, but in this climate, AM structures scored highest, surpassing CLUs in perceived protective value. Survey participants viewed AM as offering superior structural strength against heat, wind, and environmental degradation.

6. For logistical load, the results mirrored the forest scenario. Tents were seen as the least demanding, while B-Huts and CLUs required moderate upkeep. AM structures were rated as the most maintenance-intensive, particularly due to perceived complexity and uncertainty around long-term desert performance. Finally, in comfort and habitability, AM structures were again rated the highest, followed by CLUs. B-Huts provided moderate comfort, while tents scored the lowest among all respondents. The pattern mirrored the forest scenario: durable, hardened structures continue to deliver superior occupant comfort, while tents offer minimal habitability in extreme climates.

7. Surveyors were asked how confident they are that AM will be operationally viable in the next 5 years (operating outside of a controlled environment), and 25% are very confident with 25% somewhat confident, 12.5% are neutral, 31.3% are uncertain, while 6.3% are not confident. A quarter of respondents are 50% confident in a lean positive viewpoint in desert, dry conditions. They feel more confident in the development of this

environment than the previous one. A small neutral population suggested not enough available information to provide a clear trend for AM. Nearly one-third of participants are uncertain, indicating many view AM as promising but not predictable housing choice. 6.3% state they were not confident in this technology's development in the next 5 years.

8. The biggest barriers the service members see with AM housing technology in contingency operations is the barrier to providing power and water requirements to the structure. The next concern for service members is logistical constraints, equipment transportability ranking as a major barrier in austere terrain. The training and technical skills are seen as a moderate barrier. While policy or acquisition barrier is viewed as the smallest obstacle. Surveyors continued to feel power and water requirements and equipment transportability as a major barrier when fielding 3D-printed structures in contingency operations. Policy and acquisition barriers were not a real concern for the participants.

9. The survey participants were asked if they had to choose one housing type for future expeditionary operations in desert, dry environment, which would housing type would they select and why. CLUs were the most selected housing type. AM was the preferred minority answer. B-Huts rated moderately, while tents were the last option for this environment. Again, responses highly favored CLUs, however service members stated this time that soldiers needed to operate at optimal effectiveness which AM structure for longer-term or enduring operations. B-Huts, again, had sufficient support, with individuals who valued personal space and comfortability. Tents were rarely selected in this scenario, only 6.3% valued expeditious operations.

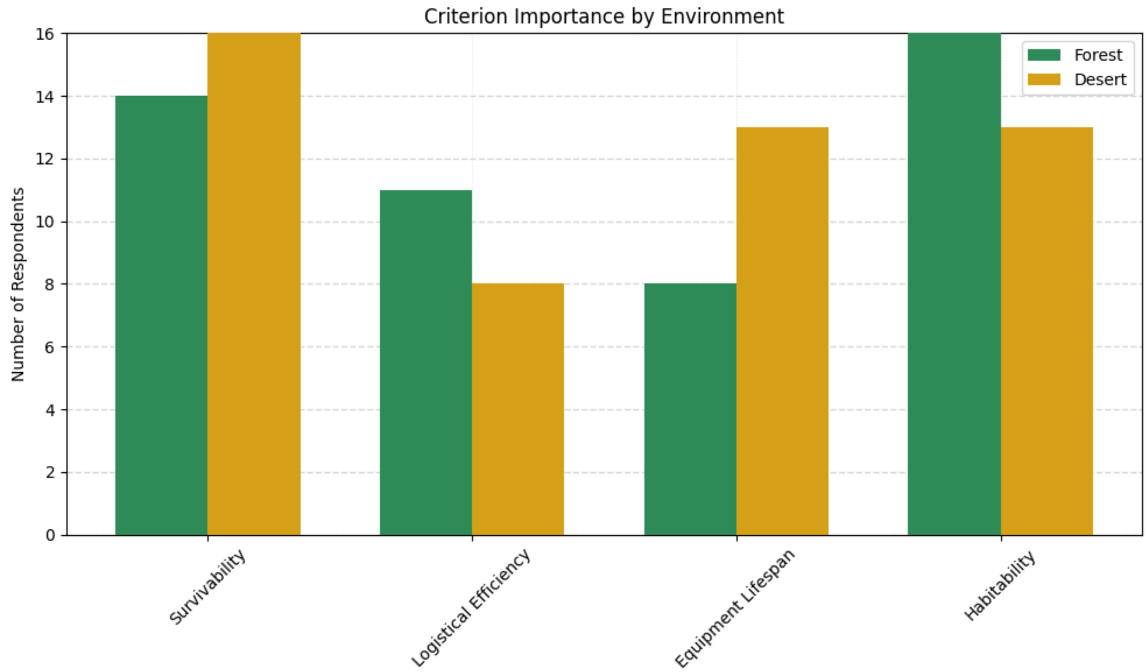

Figure 2. Survey Participant Criterion Importance

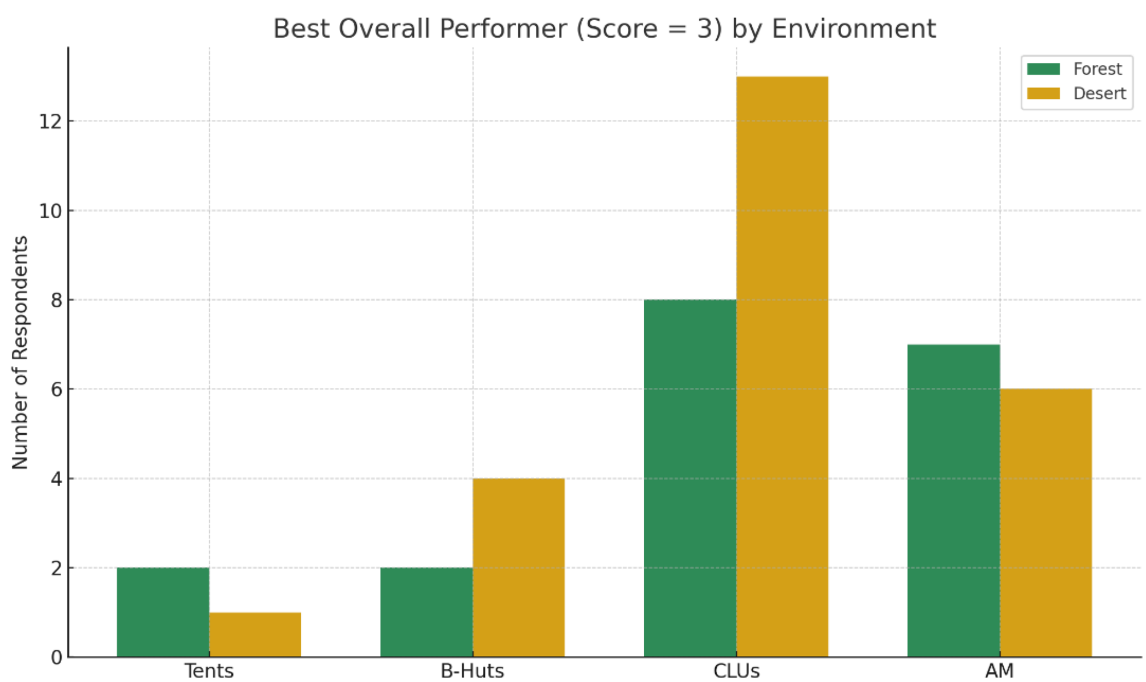

Figure 3. Survey Participant Housing Type Performance

C. MULTI-CRITERIA DECISION ANALYSIS SCORING OVERVIEW

To compare living quarter options across multiple qualitative and quantitative factors, this study applies a MCDA framework (Keeney & Raiffa, 1993; O'Loughlin, E. 2023). Four criteria, survivability, logistical footprint, equipment lifespan, and habitability, the MOEs for evaluating deployed housing systems, see Figure 4. Each criterion was assigned a priority weight based on survey responses and SME insights.

1. Gradient Scoring Scale

Figure 4. Scoring Scale Results Visual

2. Weighted Score Interpretation

MCDA weighting system assigns higher weights to criteria that represent greater operational importance and/or risk. It is normalized to a 100-percent model, as shown in Table 6, based off SME survey participants' results, my own expert observations having experience with three of the four housing types, and information collected by secondary data. The weighted score for each housing type was calculated using the formula:

$$Raw\ Score = (S \times 0.333) + (L \times 0.333) + (E \times 0.111) + (H \times 0.222).$$

Table 6. Weighted Criteria Table

Criterion*	Scoring Results	% of Total	Weighted Decimal
Survivability	3	33.3%	0.333
Logistics Efficiency	3	33.3%	0.333
Equipment Lifespan	1	11.1%	0.111
Habitability	2	22.2%	0.222
		100%	1.00

*Listed by importance

Survivability and logistics were judged most critical, each receiving a weight of 0.333, followed by habitability (0.222) and equipment lifespan (0.111). Raw weighted scores produced small decimal values difficult to interpret visually, each weight was scaled by a factor ten and rounded to the nearest whole numbers. This produced the operational weighting structure used throughout the MCDA shown on Table 7.

Again, to eliminate decimals and make comparisons clearer, raw weighted scores were **multiplied by a scaling factor of 10 to convert decimal values into whole numbers** for easier interpretation. Scaling is a standard MCDA practice and does not alter the proportional relationships or ranking outcomes. Using these weights each housing type received a performance score of 1 (low), 2 (moderate), or 3 (high) per criterion. Final weighted scores were calculated using the equation:

$$Final\ Weighted\ Score = (S \times 3) + (L \times 3) + (E \times 1) + (H \times 2).$$

This scoring method enables cross-system comparison by integrating both relative importance of each criterion and each system's performance across them. The resulting weighted totals provide a decision-support tool identifying which housing types deliver the greatest overall effectiveness under austere operating conditions, shown on Table 7 and Table 8.

Table 7. Housing Type Multi-Criteria Decision Analysis Chart

Living Quarter Types			Survivability	Logistics Efficiency	Equipment Lifespan	Habitability	**Unweighted**	**Weighted**
		Weighting	**3**	**3**	**1**	**2**		
#1:	**TEMPER**	Unweighted	1	3	2	1	7	
		Weighted	3	9	3	2		17
#2:	**CLU**	Unweighted	3	2	3	3	11	
		Weighted	9	6	3	6		24
#3:	**B-Huts**	Unweighted	2	2	2	2	8	
		Weighted	6	6	2	4		18
#4:	**AM**	Unweighted	1	2	3	3	9	
		Weighted	3	6	3	6		18

Table 8. Housing Type Comparative Performance

Housing Type	Forest/Low Plains Performance	Desert/Hot-Arid Performance	Overall differences in SME Perception
Tents	Rated lowest in: • protection • sustainability • comfort Rated highest in: • ease of deployment and sustainment burden Primary viewpoint: • best initial entry, short-term solution	Rated lowest in: • protection • sustainability • comfort Rated highest in: • ease of deployment and sustainment burden Primary viewpoint: • best initial entry, short-term solution	Lowest performing overall for enduring operations Best option for short-term mobility-focused operations
B-Huts	Rated moderate in: • protection • privacy • habitability • sustainability • humidity concerns • deployment difficulty	Rated moderate in: • protection • privacy • habitability • humidity concerns Rated high in: • Sustainment burden	Mid-range performer for enduring operations, a good option but was not the preferred Agreed it was a good option for privacy/ comfort, not necessarily for durability
AM (3D-printed)	Rated high in: • protection • privacy • habitability • sustainability • humidity concerns • deployment difficulty	Rated high in: • protection • privacy • habitability • sustainability • humidity concerns • deployment difficulty Rated moderate in: • maintenance load	High potential and strong performer. SME scored positive but guarded logistics, energy, and training constraints
CLU	Rated high in: • protection • privacy • habitability • sustainability • humidity concerns Rated moderate in: • deployment difficulty	Rated high in: • protection • privacy • habitability • sustainability • humidity concerns Rated moderate in: • deployment difficulty	Most consistently preferred shelter across both climate type scenarios

D. CONCLUSION

This chapter, we examined all four housing systems, TEMPER tents, B-Huts, CLUs, and AM structures, perform across the four criterions under two distinct operational scenarios. It demonstrates how SME preferences, environmental conditions, and MCDA scoring results. Each housing type offers a distinct operational advantage, but their suitability shifts depending on mission objective, its duration, and environmental stressors. Across both climates, the analysis showed a stable hierarchy of performance rather than scenario-dependent volatility. CLUs and AM structures repeatedly surfaced as the most capable long-term options, though for different reasons, CLUs for their proven reliability, but new information discovered on it, that even most participants were not aware of (only assumed), its automatically blast and ballistic protected. AM for its emerging potential. B-Huts remained functional but moderate, according to participants, and tents were proven to be best option predominantly for short-term, mobility-driven needs.

The final conclusion from this chapter is not which system is "best," but rather that the Army benefits from a tiered portfolio of housing options, each optimized for a different phase of operations. The MCDA results clarify where the breakpoints lie between capability, burden, and mission impact. These findings now provide the analytical foundation for Chapter V, where broader information will be addressed, and conditions for AM adoption is evaluated.

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V. DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

This chapter synthesizes the findings from the survey results, multi-criteria decision analysis (MCDA) scoring, and secondary data analysis to answer the primary and secondary research questions. It discusses how each living quarter types perform in austere conditions, assesses the feasibility of additive manufacturing (AM) relative to traditional systems, and identifies implication for policy, doctrine, and acquisition planning.

A. DISCUSSION OF FINDINGS

1. Interpretation of Multi-Criteria Decision Analysis and Survey Results

Survey responses and MCDA scoring collectively indicate a clear performance difference among the four housing types. Containerized living units (CLUs) consistently scored highest in overall effectiveness due to strong survivability, long service life, and the highest habitability rating. AM structures demonstrated strong potential in survivability and habitability but were constrained by logistical and resource requirements. Barracks huts (B-Huts) performed moderately across categories, while TEMPER tents excelled in logistical speed and mobility but remained limited in durability and protection. While survivability and habitability were initially prioritized by survey participants, weighted analysis reflecting operational requirements elevated logistical efficiency above habitability in final analysis.

2. Comparison Across Survivability, Logistics, Lifespan, and Habitability

The analysis reinforces that no single housing type is universally optimal; instead, each system offers distinct advantages aligned to specific mission requirements. CLUs and AM provide the strongest protection and environmental control but require more significant deployment resources. B-Huts provide a balance between rapid construction and moderate protection. Tents remain the most flexible and mobile option, making them valuable for short-duration or early-entry missions despite their limitations in long-term soldier welfare.

3. Conditions When Each Housing Type is Advantageous

AM becomes advantageous when mission duration exceeds several weeks, power generation is available, and perimeter security is available to reduce risk during printing. CLUs provide superior outcomes when transportation assets are available to move fully assembled modules and where long-term habitation is expected. B-Huts are advantageous when moderate durability is needed, and supply lines can support lumber transport. Tents remain the default solution for rapid establishment, short dwell times, and unpredictable tactical mobility.

4. Summary of Individual Housing Type Considerations

Collectively, these trade-offs across all four housing systems show that no single system is universally optimal. Each offers advantages tailored specific operational phases, environmental demands, and sustainment realities. The most effective housing choice depends on mission duration, threat level, environmental pressure, and available logistical capacity.

a. Tent Extendable Modular Personnel

TEMPER tents reliably scored lowest, which reflects their intended purpose: rapid entry and short-term shelter rather than enduring infrastructure. They are the most advantageous during initial entry, short-duration missions, and high-mobility operations where speed of setup, light logistical burden, and adaptability matter more than protection or durability. They are well suited for:

- rapid force projection,
- temporary command posts, and
- early-stage humanitarian or stabilization missions.

Their low performance in survivability and habitability limits usefulness beyond the initial phase.

b. Barracks Huts

B-Huts provide moderate comfort, privacy, and space, making them a reasonable option for missions lasting several months to a few years when full semi-permanent construction is not yet warranted. They are advantageous when:

- The unit expects to operate in one location for 6 months–6 years,
- The environment is relatively stable (low humidity, moderate weather), and
- The mission requires basic but not hardened structures.

Their limitations, particularly limited durability, uncertain blast/ballistic protection, and moderate logistical burden, make them less appropriate for long-term or high-threat operations.

c. Container Living Units

CLUs become advantageous when the mission requires a double, climate-controlled, and logistically manageable housing solution that provides high habitability and consistent protection. They are especially suitable for:

- The unit expects to operate in one location for 9 months–9 years,
- Environments where privacy, sanitation, and environmental control are critical, and
- Units needing structures that can be expanded, stacked, or reorganized CLUs deliver the strongest combination of survivability, habitability, and equipment lifespan, making them the most adaptable multi-environment solution despite moderate deployment demands.

d. Additive Manufacturing

AM structures become advantageous when operations require enduring, semi-permanent, or high-protection facilities, especially where traditional logistics or transportation routes are limited. AM is most beneficial when:

- Mission duration is long-term and justifies on-site construction,
- Transporting prefabricated structures is risky or impractical,
- Local aggregates or cement materials can be sourced,
- Threat levels demand higher survivability, including improved resistance to blast, environmental extremes, and structural fatigue, and
- Reducing long-term sustainment burden is a priority.

While AM carries higher initial deployment and training demands, it offers unmatched potential for customizable, resilient, and scalable infrastructure in austere environments.

B. POLICY AND ACQUISITION DOCTRINE

The findings suggest that current contingency construction doctrine (DA, 2017) does not fully account for emerging construction technologies such as AM. Integrating AM into basing policy will require updated guidance on construction timelines, power requirements, and force structure support. From an acquisition perspective, AM offers opportunities for life cycle cost savings and reduced sustainment logistics but will require targeted investment in research, equipment transportability, and training pipelines.

C. HOUSING DURATION RECOMMENDATION

1. Near-Term Recommendation (0–5 years)

After tactical motives, sustainment and HN support become the next most critical considerations when selecting a base camp location. HN willingness can dramatically influence which housing options are viable by enabling access to labor, transportation routes, and limited local resources (DA, 2017). In the near term, U.S. forces will continue to rely on non-permanent base camp solutions, which can operate for several years even though they are not intended to become long-term installations (DA, 2017, p. 1–3). Given the information from previous chapters, the recommended housing approach for 0 to 5 years is a tiered, phased model.

2. Long-Term Recommendation (5+ years)

The long-term military strategy assumes that U.S. forces will continue to operate in austere regions marked by limited infrastructure and prolonged mission requirements. As doctrine notes, contingency operations frequently extend far beyond their original intent (DA, 2017). When mission duration surpasses five years, housing requirements shift from short-term adequacy toward durability, reduced sustainment burden, and improved QOL. For operational durations beyond five years, CLUs and AM structures become the recommended primary housing solutions. Both proven and scalable options for semi-permanent and enduring missions (DA, 2017). In the end, missions exceeding five years, the recommended approach transitions toward durable, protective, and sustainable housing solutions, with AM representing the most future-ready option once doctrine, training, and acquisition pathways mature.

D. LIMITATIONS

This study relies entirely on secondary data, experiments, and SME perceptions. It limits the ability to fully validate AM performance under an actual austere environment. Also, not enough peer-review studies and field testing exist to complete insightful, detailed research, so the study requires to collect variable data to paint the best picture to the reader. Also, SME survey and experience sample size is small, non-random, and uneven in exposure of contingent basing. While their judgments helped inform MCDA but are subjective and shaped by personal experience (or lack thereof). The variability of the two environmental scenarios, while realistic, there are still many biomes to study in order to properly inform military leaders on making the best choice for their organization because this study's conclusion may not translate to all geographic climates. There was limited data on survivability, blast performance, logistical requirement, operational reliability, and training needs per system. Lastly, MCDA framework is a great source for structured insight but is subjective. It also tends to oversimplify complex engineering experiences and criteria to make them comparable. However, there are trade-offs that highly differ from one another.

E. AREAS FOR FUTURE RESEARCH

There is currently a lot of room for research expansion in this area, such as full-scale field trials in operational environments. Currently, Engineer Research and Development Center (ERDC) is conducting studies but are focused on controlled environments but consistently pushing the envelope to hopefully begin deployment of equipment into austere environments. Another area of improvement, as stated prior to, it is new technology which requires long-term durability assessment and material degradation studies. The best study is those that track 1 to 5+ years of realistic degradation to measure accurate data and maintenance profile. Another area to seek future research in this is to strictly focus on supply chain and material innovation.

F. CONCLUSION

This study evaluated four deployed housing systems, TEMPER tents, B-Huts, CLUs, and 3D-printed modular barracks, to determine which best supports soldier readiness and operational effectiveness in austere environments. Using a mixed qualitative approach that combined SME surveys, scenario-based assessments, and a weighted MCDA framework, the analysis demonstrated clear performance distinctions across survivability, logistics, lifespan, and habitability.

Across all criteria, CLUs delivered the highest overall effectiveness, offering strong protection, durability, and habitability for missions requiring extended dwell.AM showed significant promise where power, time, and secured construction space are available. Its structural resilience and habitability scores suggest AM could become a superior option for semi-permanent or long-term contingency basing once logistical and power constraints are reduced. B-Huts provided moderate performance in durability and habitability but remained limited by material transport and manpower demands. TEMPER tents proved most advantageous only in early-entry or short-duration missions where mobility and rapid deployment outweigh survivability and comfort needs.

The results indicate that no single housing type is universally optimal. Instead, effectiveness depends on mission duration, available infrastructure, and environmental conditions. AM is not yet full replacement for current systems, but under the right conditions, stable power, protected build time, and engineer support, it can meaningfully improve soldier welfare and reduce long-term sustainment demands. As AM technology matures, it is poised to transition from an experimental capability to a viable option for future contingency construction.

The research set out to evaluate whether AM can feasibly serve as an alternative or complementary solution to current housing options in an austere environment. By combining doctrinal analysis, a structured MCDA framework, and insights from a diverse SME survey population, the study provides a grounded assessment of how TEMPER tents, B-Huts, CLUs, and AM structures perform across operationally relevant criteria. Two climates evaluated, to study realistic conditions, and the results were consistent, and can explore focal point criteria when it comes to living quarters for warfighters. CLUs emerged as the most balanced and reliable system of the four types. It scored the best in survivability, livability, and equipment longevity while maintaining manageable logistical requirements. AM structures consistently ranked as closed second, offering good protection and habitability but demonstrated constraints, particularly in the area that lacked enough research information and experience due to its immaturity. Personnel have limited knowledge of this method and is apparent even within the study.

The research concludes that AM is not yet universal replacement for existing housing systems, but it has a high-potential, and valuable capability for enduring missions. As AM technology matures its advantages is in structural resilience and progressive supply chain, that may significantly reshape the DoD in future expeditionary infrastructure. It remains with challenges, its trajectory from prototyping to deployment in controlled environments to advance the collection of data. In the end, AM is not a one-for-one replacement for existing contingency housing, but it is viable and increasing as a credible option for improving soldier readiness, protection, and quality of life in medium- to long-duration operations. Continued research, doctrinal updates, and targeted investment in deployable AM capability. Finally, the Army can leverage AM to reduce sustainment burdens, enhance force protection, and modernize the way DoD establishes and maintains deployed living quarters.

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