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Design, Validation and Production of an Edge Device Chassis for Machine Tools

Constraint-Driven Architectural Definition of a Machine-Integrated Enclosure

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Abstract

This thesis presents the constraint-driven architectural definition of an industrial edge device enclosure for direct integration within CNC machining environments. As compute-scale hardware migrates from protected electrical cabinets to machine-adjacent deployment, enclosure design can no longer function as neutral packaging. Environmental exposure, DIN-rail logic, predefined electronics, vibration, and subtractive manufacturability are treated as fixed boundary conditions structuring the design space from the outset.

Rather than optimising geometry after form generation, the project establishes internal organisation, spatial hierarchy, load paths, airflow intent, and assembly logic prior to external articulation. Geometry therefore emerges from component envelopes, interface standards, thermal sources, and installation constraints, producing a monolithic configuration whose mass distribution and vent topology reflect structural and thermal necessity rather than stylistic intent.

Formal development proceeds in explicit relation to five-axis CNC milling. Tool accessibility, machining stability, feature radii, tolerance localisation, and fastening engagement act as geometric filters. Aluminium 7075 is adopted as a declared material boundary condition, stabilising interpretation of stiffness, load transfer, and heat spreading within a machine-adjacent context.

Engineering validation is positioned as an interpretive exercise conducted after architectural resolution. Simplified structural and airflow analyses assess mechanical plausibility, modal tendencies, ventilation coherence, and pressure behaviour under representative operating conditions. Simulation serves to exclude adverse behaviour and confirm internal consistency rather than to drive optimisation or certification claims.

The outcome is a coherent enclosure architecture inseparable from its internal system definition, manufacturing domain, and operational realities. The thesis demonstrates a disciplined methodology in which constraint functions as a generator of architectural clarity, establishing a credible baseline for machine-integrated industrial hardware.

Abstract (Italiano)

Questa tesi presenta la definizione architettonica guidata da vincoli di un involucro per dispositivo edge industriale destinato all'integrazione diretta in ambienti CNC. Con la migrazione dell'hardware di calcolo da quadri elettrici protetti verso installazioni adiacenti alla macchina, l'involucro non può più essere considerato un contenitore neutro. Esposizione ambientale, installazione su guida DIN, architettura elettronica predefinita, vibrazioni e lavorazione sottrattiva sono assunte come condizioni al contorno non negoziabili che strutturano il progetto fin dall'origine.

Invece di ottimizzare la geometria dopo la definizione formale, il progetto stabilisce organizzazione interna, gerarchia spaziale, percorsi di carico, flusso d'aria e logica di assemblaggio prima dell'articolazione esterna. La geometria emerge dagli ingombri dei componenti, dagli standard di interfaccia, dalle sorgenti termiche e dai vincoli di installazione, generando una configurazione monolitica in cui distribuzione della massa e topologia delle aperture rispondono a necessità strutturali e termiche più che a scelte stilistiche.

Lo sviluppo formale procede in relazione alla fresatura CNC a cinque assi. Accessibilità utensile, stabilità in lavorazione, raggi di raccordo, localizzazione delle tolleranze e interfacce filettate agiscono come filtri geometrici. L'alluminio 7075 è adottato come condizione materiale dichiarata, stabilizzando l'interpretazione di rigidezza, trasferimento dei carichi e diffusione termica in contesto macchina-adiacente.

La validazione ingegneristica è impostata come esercizio interpretativo successivo alla definizione architettonica. Analisi strutturali e fluidodinamiche semplificate valutano plausibilità meccanica, tendenze modali, coerenza ventilativa e comportamento pressorio in condizioni operative rappresentative. La simulazione conferma la coerenza fisica senza costituire ottimizzazione o certificazione.

Il risultato è un'architettura coerente in cui geometria, sistema interno, dominio produttivo e contesto operativo risultano inseparabili, dimostrando un metodo in cui il vincolo diventa generatore di chiarezza architettonica per hardware industriale integrato alla macchina.

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List of Abbreviations

CNC Computer Numerical Control

CPU Central Processing Unit

GPU Graphics Processing Unit

PCIe Peripheral Component Interconnect Express

DIN Deutsches Institut für Normung

TS 35 35 mm top-hat DIN rail profile

IEC International Electrotechnical Commission

ISO International Organization for Standardization

ETSI European Telecommunications Standards Institute

IP Ingress Protection

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASME American Society of Mechanical Engineers

ASTM ASTM International

IEEE Institute of Electrical and Electronics Engineers

DFMEA Design Failure Mode and Effects Analysis

CFM Cubic Feet per Minute

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01

Introduction

This chapter establishes the industrial context and boundary conditions governing machine-integrated edge device enclosures, framing architecture as a constraint-driven problem shaped by environmental exposure, structural coupling, thermal behavior, and manufacturability.

Chapter 1

Introduction

Industrial Context and Architectural Problem Definition for Machine-Integrated Edge Devices

1.1 CNC Machining Environments in Digital Manufacturing

CNC machining environments represent one of the most physically demanding contexts within contemporary digital manufacturing, not because of isolated extreme events, but due to the persistence and simultaneity of multiple stress-inducing phenomena. Modern machine tools operate under high material removal rates, multidirectional cutting forces, and prolonged duty cycles characteristic of automated production systems. Hardware deployed in proximity to these machines is therefore subjected to operating conditions that act continuously and cumulatively over time rather than as rare or accidental anomalies [1, 2].



Figure 1.1: CNC Production Floor Context

Such environments impose a combination of physical stressors, including airborne metal chips generated during cutting operations, liquid coolants used for lubrication and thermal control, and mechanical vibrations transmitted through spindles, machine frames, and

shop-floor foundations. Although each stressor acts through a different physical mechanism, they converge in their effect on nearby equipment by reducing the predictability and stability of interfaces, surfaces, clearances, and assemblies. For hardware integrated close to the machining process, this loss of environmental predictability becomes a defining design condition rather than a secondary consideration [1].

Cutting fluids, typically oil–water emulsions or synthetic formulations, are continuously circulated and atomized during machining. Mist and splashing deposit films on surrounding surfaces and migrate into crevices, joints, and interfaces. Fluid residues alter friction conditions at mechanical interfaces, promote contaminant accumulation, and create conductive or corrosive paths in regions where electronic connectors depend on stable surface conditions [3]. In this context, enclosure openings, joints, and seams become active interfaces whose geometry and orientation influence long-term reliability.

In parallel, metal chips are expelled at high velocity and accumulate dynamically around the machine. Fine particulate debris behaves as an abrasive contaminant capable of clogging vents and eroding exposed edges, while larger fragments introduce localized impact and wedging risks at openings and recesses. Ventilation and access strategies therefore cannot assume interaction with a benign ambient environment. Geometry must explicitly manage ingress pathways, debris trajectories, and accumulation zones [1, 2].

Mechanical vibrations propagate through machine structures and supporting foundations and are often amplified during high-speed operations and aggressive toolworkpiece interactions. These vibrations introduce fluctuating mechanical loads into equipment mechanically coupled to the machine. The primary concern is not immediate structural failure but cumulative architectural consequences: gradual fastener preload variation, fretting at contact interfaces, fatigue initiation at stress concentrators, and unintended resonance of slender features [4, 5]. Over extended operating periods, such effects directly influence decisions related to mass distribution, stiffness continuity, and interface definition.

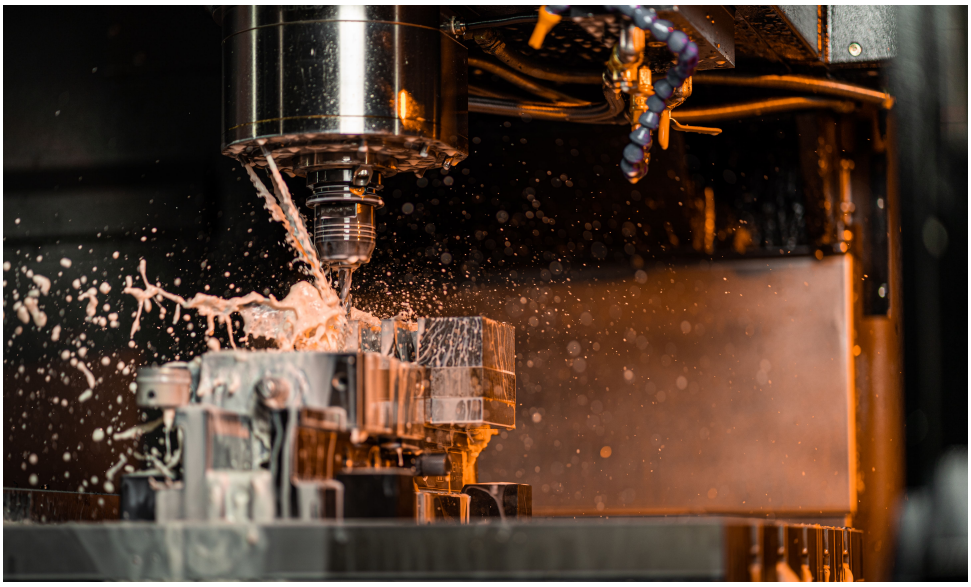


Figure 1.2: CNC Machining Environment

CNC shop-floor environments are additionally characterized by continuous operation, variable thermal conditions, and fluctuating humidity levels associated with coolant use and ventilation practices. Thermal cycling, condensation risk, and residue formation emerge as persistent phenomena rather than exceptional events. For electronic equipment operating in close proximity to machining processes, these conditions introduce enduring challenges related to material compatibility, mechanical durability, thermal behavior, and interface stability. The machining environment therefore resists abstraction and must be treated as a first-order constraint conditioning the physical configuration of hardware intended for machine-adjacent deployment.

1.2 Edge Devices as Physically Embedded Nodes in Distributed Monitoring

Within digital manufacturing and Industry 4.0 architectures, industrial edge devices function as distributed computational nodes responsible for acquiring, processing, and relaying data at the point of production. Their value lies in locality: by performing computation close to the process, edge devices reduce reliance on centralized infrastructures, enable lower-latency data handling, and support responsive monitoring, anomaly detection, and adaptive control strategies [6, 7].

Unlike centralized servers or purely virtualized systems, industrial edge devices are deployed in direct physical proximity to machine tools and production assets. They are integrated into shop-floor infrastructurecontrol cabinets, machine frames, or auxiliary mounting structuresto access sensor data generated during operation [6]. This physical embedding is not incidental. It fixes spatial orientation, constrains access directions, defines mounting interfaces, and mechanically couples the device to the surrounding machine environment.

As edge computing hardware migrates from protected electrical cabinets toward machine-adjacent installation, longstanding assumptions underlying enclosure design begin to erode. Cabinet-level protection, shared airflow volumes, and isolated vibration environments can no longer be presumed. The architectural separation between computation and machine structure is reduced, and enclosure logic must respond accordingly.

Because the device is physically embedded, it must reconcile domains often treated independently. It must execute computational logic and maintain reliable connectivity with high-frequency data streams, while remaining mechanically stable under vibration, enabling predictable thermal behavior under sustained internal heat generation, and regulating environmental exposure at openings and interfaces. The industrial edge device therefore occupies a hybrid position: simultaneously a computing node and a material artefact subject to load paths, contamination mechanisms, and assembly constraints.

Data continuity and computational reliability are preserved only if the artefact hosting them maintains mechanical integrity, thermal compatibility, and service accessibility under shop-floor conditions. The design problem is therefore not limited to housing electronics, but to mediating between computation, environment, manufacturing practice, and use through a coherent physical configuration.

1.3 Project Objectives and Design Intent

This design-led thesis pursues the architectural definition and formal development of an industrial edge device intended for direct integration within CNC machining environments. The investigation assumes a production and deployment context typical of low-to-medium volume industrial monitoring equipment, where precision CNC machining and standardized mounting practices are established realities. These contextual assumptions are treated as boundary conditions rather than variables to be optimized.

The work is guided by predefined electronic components, installation imperatives, and operating conditions that are treated as fixed inputs. Within this framework, the primary objective is to establish a constraint-driven design approach in which environmental exposure, structural behavior, thermal behavior, and manufacturing conditions actively structure internal organization, geometric definition, and assembly logic from the earliest stages of development.

The central contribution of the thesis lies in resolving the enclosure as a coherent architectural system rather than as a neutral protective shell. Internal spatial hierarchy, load-bearing interfaces, airflow intent, access strategy, and manufacturing feasibility are developed in parallel, allowing geometry to emerge from internal necessity rather than stylistic preconception. Design decisions are justified through their relationship to constraints, interfaces, and lifecycle considerations rather than through formal optimization.

1.4 Scope, Boundaries, and Declared Ownership of the Investigation

The scope of the thesis includes the definition of system architecture around a fixed electronic layout, the organization of internal spatial relationships, the development of external geometry as a consequence of physical constraints, and the refinement of the enclosure under defined manufacturing conditions. Material selection, fastening strategy, and assembly and installation logic are treated as integral components of the architectural definition.

Chapters addressing engineering verification, reliability awareness, and production considerations are included to preserve coherence and physical credibility, but they do not constitute the primary focus. Engineering analysis is employed as an interpretive instrument to confirm physical plausibility, expose limits, and exclude structurally adverse conditions, without repositioning validation as the origin of geometry.

The thesis does not pursue certification-level validation or exhaustive numerical optimization. Analysis interrogates design decisions already established architecturally. Explicitly excluded are electronic circuit design, firmware or software development, digital twin modeling, and performance benchmarking of computational algorithms.

These boundaries ensure that the investigation remains centered on the physical and architectural dimensions of industrial edge-device design, where intent is preserved through material definition, environmental mediation, interface stability, and maintainable assembly.

02

Operating Conditions and Design Constraints

This chapter establishes environmental classification, DIN-rail installation logic, vibration exposure, and predefined electronic architecture as fixed boundary conditions shaping the enclosure design space. It treats these constraints as primary architectural drivers rather than secondary verification parameters.

Chapter 2

Operating Conditions And Design Constraints

2.1 Environmental Operating Conditions For Machinery-Mounted Electronics

Electronic equipment deployed in proximity to industrial machine tools operates within environmental conditions that differ substantially from both office-grade installations and electronics housed inside sealed electrical cabinets. In CNC machining facilities, even devices mounted outside the primary cutting envelope remain exposed to the ambient characteristics of the factory hall, including airborne particulates, oil mist, humidity fluctuations, and sustained thermal variation associated with continuous operation. These conditions act persistently over time and cannot be treated as rare or accidental disturbances [8].

International standards provide a structured framework for characterizing such environments without assuming direct exposure to weather or process fluids. IEC 60721-3-3 defines environmental severity classes for stationary use at weather-protected locations, including production halls where oil mist, dust, and uncontrolled humidity are present [8]. Environments corresponding to Class 3K3 are characterized by moderate concentrations of airborne contaminants, relative humidity variation, and temperature ranges typical of industrial interiors, while explicitly excluding direct exposure to liquid jets or solid particle impact. This classification aligns with electronic equipment mounted on or near machine tools but outside the machining enclosure.

Environmental parameter	**Unit**	**3K3**	**3K5**
Low air temperature	°C	+5	-5
High air temperature	°C	+40	+45
Low relative air humidity	%	5	5
High relative air humidity	%	85	95

Table 2.1: Environmental severity parameters according to IEC 60721-3-3 (Classes 3K3 and 3K5).

Rather than prescribing specific design solutions, these classifications establish the baseline environmental envelope within which machinery-mounted electronics are expected to

operate reliably. Indirect contaminationoil aerosols settling on surfaces, fine dust ingress, and condensation driven by temperature cyclingconstitutes a persistent operating condition rather than an exceptional event. Over extended service life, such exposure can influence material degradation, connector reliability, and thermal performance even in the absence of direct coolant or chip contact [8].

Complementing environmental classification, the IEC 60068-2 series defines standardized test methods used to evaluate electronic equipment subjected to temperature cycling, humidity variation, and mechanical disturbance. IEC 60068-2-30 formalizes cyclic damp heat exposure, representing condensation and moisture-related stresses encountered in industrial interiors [9]. While these standards do not describe operational environments directly, they reinforce the interpretation of environmental exposure as repeatable and technically characterizable, supporting the treatment of environmental conditions as primary design inputs rather than post-hoc verification concerns.

A parallel environmental classification is provided by ETSI EN 300 019-1-3, which defines controlled indoor environments for telecommunications and industrial electronics deployed at weather-protected locations [10]. The temperature and humidity ranges specified for Class 3K3 and 4K3 environments corroborate the positioning of machinery-mounted electronics within factory halls rather than within sealed cabinets or outdoor installations. Together, these standards establish a clear distinction: machinery-mounted electronics are protected from direct process hazards, yet continuously exposed to the ambient realities of industrial production spaces. Environmental conditions are therefore treated as persistent operating factors that shape enclosure configuration, material selection, and thermal strategy from the outset.

2.2 DIN Rail Mounting As An Installation Constraint

Installation requirements exert a decisive influence on the physical configuration of industrial electronic devices. In the present context, DIN rail mounting is treated as an imposed system constraint reflecting established industrial practices for modularity, interchangeability, and serviceability. IEC 60715 standardizes the geometry of DIN rails, defining uniform profilesmost commonly the 35 mm top-hat railthat enable snap-fit mounting of modular electronic equipment [11]. Compliance with this standard constrains device dimensions to discrete increments aligned with rail width and retention mechanisms, bounding the allowable footprint, depth, and interface placement of the enclosure.

DIN rail systems are typically installed horizontally on vertical mounting panels, leading to upright device orientation and front-facing access [11]. This configuration introduces non-negotiable access and clearance constraints. Connectors, indicators, and service interfaces are expected to be accessible from the front face, while lateral clearance must be preserved to allow adjacent modules to be installed or removed without disturbing neighboring equipment. Requirements related to maintainability and safe servicing, as articulated in IEC 60204-1, reinforce expectations of standardized spacing and predictable access within modular assemblies [12].



Figure 2.1: TS 35 DIN Rail Geometry and Engagement Logic.

Thermal behavior is also implicitly conditioned by DIN rail installation practice. Manufacturer guidelines commonly recommend minimum vertical spacing between adjacent modules to support natural convection in vertically mounted assemblies. Siemens documentation for DIN rail-mounted systems specifies vertical gaps on the order of 1020 mm and introduces thermal derating considerations at elevated ambient temperatures [13]. These recommendations assume heat dissipation partly supported by buoyancy-driven airflow aligned with gravity. Enclosure geometry, vent placement, and internal layout are therefore constrained before any specific cooling strategy is defined.

Mechanical stability under vibration further conditions DIN rail-mounted equipment. Environmental classifications within IEC 60721-3-3 and vibration test standards such as IEC 60068-2-6 assume secure retention of snap-mounted devices to prevent loosening or disengagement under continuous excitation [8, 14]. For equipment mounted directly on machinery or machine frames, the DIN rail interface becomes a critical mechanical boundary through which dynamic loads are transmitted into the enclosure. In this thesis, DIN rail mounting is treated as a system-level interface constraint governing spatial organization, access logic, airflow directionality, and mechanical coupling, shaping the design space within which the enclosure architecture is developed.

2.3 Vibration Exposure In Heavy CNC Machine Installations

Vibration constitutes a defining characteristic of machinery-mounted electronic equipment, particularly when installed on heavy, floor-mounted CNC machines. Unlike shock events

associated with transport or accidental impacts, vibration in this context arises primarily from structure-borne excitation generated during normal machine operation. IEC 60721-3-3 classifies vibration severities for stationary equipment in industrial environments, distinguishing between continuous low-level vibration and superimposed transient events [8]. In production halls housing large machine tools, vibration is transmitted through machine frames, foundations, and mounting structures, resulting in persistent excitation across low- to mid-frequency ranges.

The continuous nature of such excitation introduces cumulative effects relevant to enclosure design, including fatigue initiation, fastener preload variation, and potential resonance amplification in slender or poorly supported features. IEC 60068-2-6 formalizes sinusoidal vibration testing representative of rotating machinery and structural coupling [14], while IEC 60068-2-64 addresses broadband random vibration associated with mixed operational spectra and transient disturbances linked to machine dynamics such as spindle acceleration, tool changes, and axis motion [15]. Vibration exposure is therefore framed not as a singular load case but as a combination of background excitation and intermittent events that must be considered architecturally.

Complementary guidance is provided by ISO 10816-3, which categorizes vibration levels associated with large, floor-mounted industrial machines based on measurements taken on non-rotating parts [16]. Although primarily intended for machine condition monitoring, this classification underscores the magnitude and persistence of vibration present in heavy CNC installations. For enclosure design, the implication is not merely the need to withstand vibration, but to avoid amplifying it through unfavorable mass distribution, stiffness discontinuities, or interface geometry. Vibration is therefore treated as a continuous operating condition constraining structural configuration and internal component arrangement rather than as an exceptional load addressed through localized reinforcement.

2.4 Predefined Electronic Architecture And Internal System Constraints

The internal electronic configuration of the device is treated as a predefined subsystem established prior to, and independently from, enclosure development. The electronic architecture is based on standardized embedded computing components selected to support local data processing typical of industrial edge applications. The role of the enclosure is not to redefine electronic functionality, but to integrate these components physically within a machinery-mounted context while respecting their fixed envelopes, interfaces, and operating requirements.

The system is organized around a single mini-ITX motherboard hosting the central processing unit, memory modules, and primary expansion interfaces. Expansion capability is provided through a single-slot PCIe graphics processing unit mounted directly to the motherboard. To mitigate mechanical loading on the PCIe connector under structure-borne vibration, a secondary retention element establishes an alternative load path that decouples electrical connectivity from structural restraint. Power delivery is provided by a

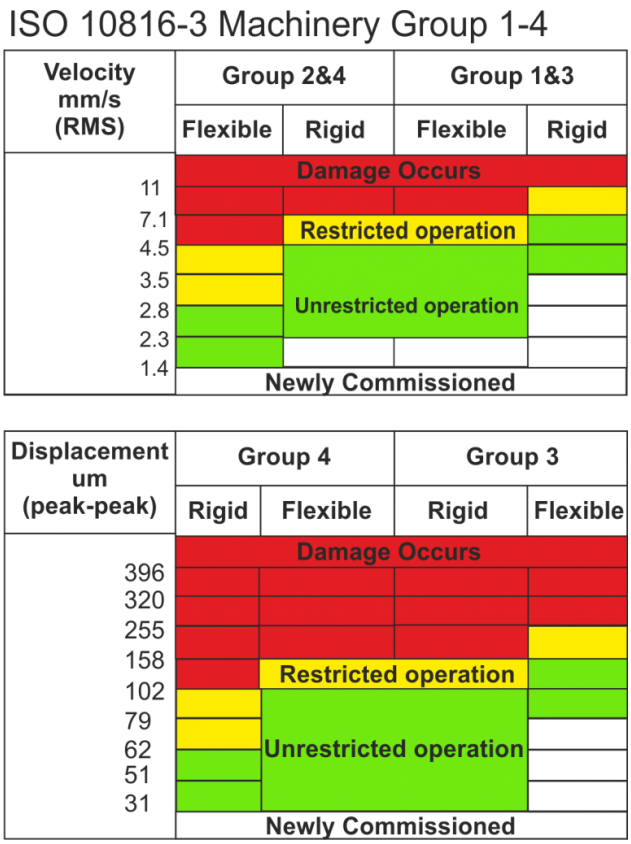


Figure 2.2: Vibration Classification Zones (ISO 10816).

separate, passively cooled power supply unit mounted as an independent module within the enclosure, introducing a localized thermal load dependent on enclosure-level airflow rather than dedicated forced cooling.



Figure 2.3: Declared Electronic Component Set and Spatial Arrangement

Together, the processing unit, graphics module, and power supply establish a system characterized by spatially concentrated heat sources with differing cooling dependencies. Active cooling is mandatory for the central processor, while the graphics unit and power supply rely on a combination of local airflow and overall enclosure ventilation. Airflow is therefore treated as a system-level requirement rather than an isolated component feature.

External interfaces and fastening points are defined by the internal architecture and imposed installation logic, leading to front-face connector access consistent with vertical DIN rail mounting practices. Internal volume is allocated for cable routing tolerance and strain relief, acknowledging variability in harness stiffness, connector geometry, and service practice.

The predefined electronic architecture establishes non-negotiable internal constraints: fixed component envelopes and interface locations, localized thermal generation, mixed active and passive cooling dependencies, and mechanically sensitive expansion interfaces. These constraints precede enclosure form and directly inform system architecture, internal layout, and structural strategy. The enclosure is therefore developed as an adaptive structure responding to defined electronic content rather than as an abstract housing into which components are subsequently fitted. Resolution of the resulting thermal and mechanical couplings is addressed in subsequent architectural development and engineering assessment.

03

Reference Analysis and Architectural Requirement Definition

This chapter analyses existing industrial enclosure typologies and identifies limitations when compute-scale systems are machine-mounted. It derives explicit architectural requirements addressing thermal management, airflow definition, vibration stability, serviceability, and manufacturing compatibility.

Chapter 3

Reference Analysis And Architectural Requirement Definition

3.1 Typologies Of Existing Monitoring And Enclosure Solutions

Industrial monitoring and edge-computing devices deployed on shop floors are typically realized through a limited number of recurring solution typologies. Each typology reflects implicit assumptions regarding installation context, environmental exposure, thermal behavior, and access philosophy. These solutions are examined here not in terms of computational performance, but as physical artefacts whose enclosure strategies encode expectations about operating conditions.



(a) (b)

Figure 3.1: Typological comparison of existing enclosure strategies: (a) cabinet-mounted edge computing enclosure; (b) IP-rated sealed enclosure.

A first typology comprises industrial edge-computing boxes used as gateways or local processing nodes. These devices are typically wall- or panel-mounted and rely on passive or lightly assisted airflow. Their enclosures are conceived for weather-protected interiors, presupposing moderate ambient temperatures, limited contamination, and the availability of surrounding air volume for convection, consistent with standardized indoor enclosure classifications [17]. Maintenance is generally periodic and scheduled.

A second typology includes DIN-rail-mounted compute and control devices forming the backbone of modular industrial automation systems. Dimensioned around standardized rail profiles and most commonly installed within electrical cabinets, these devices prioritize compactness, snap-fit mounting, and ease of replacement within dense assemblies [18]. Thermal behavior is typically addressed through vertical convection paths between adjacent modules, presupposing controlled airflow and cabinet-level spacing. Environmental exposure is assumed to be indirect and regulated.

A third typology consists of IP-rated industrial enclosures intended to house electronic equipment in production areas. These solutions emphasize containment and environmental protection, offering resistance to dust, oil mist, and occasional splashes through sealed construction [19]. Typically realized as sheet-metal or polymer boxes incorporating gaskets and hinged access, they assume relatively low internal power dissipation or rely on auxiliary cooling elements. Access is generally infrequent and tool-assisted.

A final typology encompasses machine-mounted monitoring units designed for direct proximity to machining processes. These devices are compact, ruggedized, and sealed, optimized for low-power sensing electronics capable of tolerating vibration and contamination. Their enclosures emphasize robustness and long-term embedding rather than serviceability, and they are not intended to accommodate compute-scale heat generation or frequent human interaction.

Taken together, these typologies demonstrate that enclosure architecture is strongly shaped by presumed installation context. Each solution is effective within its intended domain. However, their embedded assumptions become structurally significant when devices are relocated from protected cabinets or peripheral locations to direct machine-mounted configurations.

3.2 Limitations Of Current Approaches In Machine-Mounted Integration

When evaluated through the lens of direct integration on CNC machinery, recurring limitations emerge. These limitations arise not from inadequate engineering, but from mismatches between enclosure assumptions and machine-mounted deployment realities.

A primary limitation concerns thermal management. Many industrial edge devices and sealed enclosures are conceived for low to moderate power dissipation, relying on ambient air circulation, cabinet-level convection, or containment strategies that restrict airflow. When compute-scale electronics are introduced, sustained internal heat generation leads to temperature rise unless defined airflow paths are provided. Fully sealed enclosures,

while effective at contamination control, inherently constrain heat rejection and shift the challenge toward internal hotspot formation [20].



Figure 3.2: Thermal Constraint in Fanless Architecture

A second limitation relates to airflow dependency. DIN-rail systems and cabinet-mounted devices often rely on vertical chimney effects and shared airflow volumes available only in controlled assemblies. Manufacturer guidance for DIN-rail thermal management assumes vertical convection paths and prescribed inter-module spacing within cabinets [21]. When mounted directly on machine frames or within constrained envelopes, these assumptions may no longer hold, rendering passive convection unreliable.

Mechanical integration under vibration presents a further challenge. Snap-fit mounting systems and lightweight housings are well suited to static installations, but continuous structure-borne vibration introduces additional demands on retention, load distribution, and fatigue resistance. Existing solutions seldom address vibration as a persistent enclosure-level operating condition when combined with increased mass from compute hardware.

Serviceability introduces an additional conflict. Solutions optimized for cabinet installation assume controlled, clean access. Sealed machine-mounted units assume minimal intervention. In machine-adjacent compute deployments, maintenance may be required without removing the device from its mounting interface and without exposing internal components to contamination. Existing strategies tend to prioritize either accessibility or protection, but rarely reconcile both within a unified architectural configuration.

Collectively, these limitations indicate that the central challenge is not electronic capability, but the absence of enclosure architectures capable of reconciling compute-scale thermal loads, vibration exposure, airflow dependency, and service access within the spatial and environmental constraints of CNC machine environments. The architectural assumptions underpinning conventional typologies do not directly translate to machine-integrated compute deployment.

3.3 Derivation Of Architectural Design Requirements

The integration limitations identified above lead to a set of architectural design requirements. These are not optional enhancements but necessary responses to the operating context

defined in Chapter 2 and to the structural gaps observed in existing typologies.

First, the enclosure architecture must support sustained heat rejection compatible with industrial ambient conditions without exclusive reliance on cabinet-level airflow or external HVAC systems. Thermal management must be treated as a system-level concern integrating component cooling, enclosure-mediated airflow, and conductive heat-spreading strategies.

Second, airflow paths must be explicitly defined and preserved within enclosure geometry. Rather than assuming full sealing or unrestricted convection, the architecture must enable controlled ventilation that balances heat rejection with mitigation of indirect contamination.

Third, mechanical interfaces and mounting strategies must ensure stable retention under continuous vibration. Load paths should distribute structural forces such that mechanically sensitive elect

04

System Architecture and Internal Organisation

This chapter defines internal system architecture based on fixed commercial components and installation constraints prior to external form development. It establishes spatial hierarchy, interface logic, service access strategy, and airflow intent governing subsequent geometric resolution.

Chapter 4

System Architecture And Internal Organisation

4.1 Architecture Derived From Fixed Components

The system architecture of the edge device is derived directly from a fixed set of electronic components and installation constraints treated as non-negotiable inputs. Architecture is understood here as the structured organization of system elements and their relationships under defined constraints, rather than as the outcome of geometric optimization or performance tuning [22].

The device integrates a mini-ITX motherboard hosting the central processing unit, memory, and primary storage; a single-slot PCIe graphics card with dedicated mechanical retention; and a passively cooled power supply realized as an independent module. No daughterboards or auxiliary compute modules are introduced. This deliberate limitation ensures that architectural decisions are driven by integration logic and interface coherence rather than by component proliferation.

The motherboard is oriented vertically relative to gravity, establishing a spatial reference for component stacking, cable routing, and airflow intent. The graphics card interfaces through a standard PCIe connection and is mechanically supported to decouple connector loads from vibration-induced stresses. The power supply unit is positioned adjacent to the motherboard as a screwed sub-assembly, localizing power distribution while preserving modular replacement. Together, these elements define a compact but heterogeneous internal system in which compute, power, and support functions coexist within a constrained volume.

At the installation level, the enclosure interfaces with the machine via a standardized TS 35 DIN rail mounted on the rear face through a dedicated bracket [11]. Treating the DIN rail as an external interface modulerather than as an integral geometric featureallows the enclosure body to remain structurally coherent while accommodating standardized mounting practice. Installation constraints are therefore absorbed at the boundary without dictating internal organization.

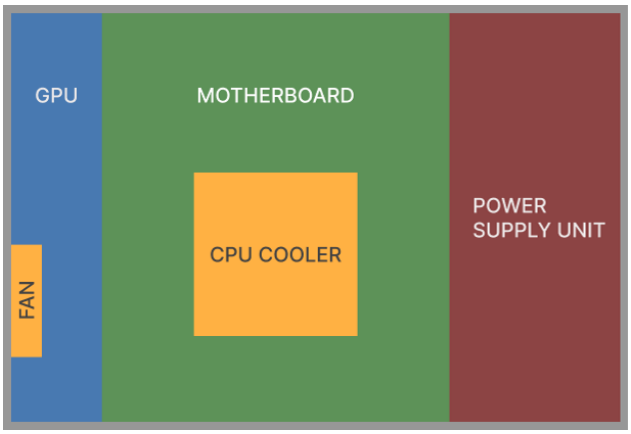


Figure 4.1: Internal System Architecture and Functional Zoning

4.1.1 Declared Electronic Components And System Contents

The internal architecture is constrained by an explicitly declared set of commercial off-the-shelf electronic components selected prior to enclosure formalization. Their dimensions, interface standards, thermal characteristics, and installation requirements collectively establish the volumetric envelope, internal clearances, and interface logic of the enclosure.

The compute platform is based on a mini-ITX motherboard (ASUS ROG Strix B650E-I Gaming WiFi), which fixes the primary planar footprint and defines I/O locations and mounting points. Processing is provided by an AMD Ryzen 9 7900 processor, constituting the dominant thermal load and dictating cooling strategy, airflow intent, and clearance above the motherboard plane. Memory modules influence stacking height and local clearance but contribute limited thermal output.

Graphical processing is handled by an NVIDIA A1000 single-slot PCIe graphics card. The single-slot constraint limits enclosure depth while enabling dedicated GPU capability. The graphics card introduces localized airflow requirements and necessitates mechanical support to decouple the PCIe connector from vibration and handling loads. Mass storage is provided by a Lexar NM790 4 TB M.2 PCIe Gen4 solid-state drive mounted directly on the motherboard, eliminating auxiliary cabling while contributing localized heat generation.

CPU cooling is achieved using a low-profile Noctua NH-L9x65 chromax.black air cooler. Its height and airflow orientation impose limits on enclosure depth and inform the placement of primary ventilation features on the front panel. Power delivery is handled by an HDPLEX 250 W GaN passive AIO ATX power supply. As a passively cooled unit, it introduces spatial and thermal constraints requiring clearance for natural convection and conductive heat transfer while enabling a compact fanless architecture [23].

Electrical power entry is provided through an IEC C14 panel-mount inlet, while user control is realized via a 22 mm flush-mount push-button switch. These boundary components define minimum wall thicknesses, cut-out geometries, and local reinforcement requirements at the enclosure interface.

By fixing the component set at this stage, enclosure design is driven by integration, clearance, and interface requirements rather than abstract dimensional targets. External

form is therefore treated as a direct consequence of declared system contents.

4.2 Functional Roles And Spatial Relationships

Within the enclosure, components are organized according to functional roles rather than geometric symmetry. The processing subsystem, CPU and GPU forms the primary computational and thermal core. The power subsystem constitutes a secondary heat source with distinct spatial and service requirements. Supporting elements such as memory and storage remain integrated within the motherboard envelope.

A defined service access zone is established at the front of the enclosure. The front panel is conceived as a single removable plate, enabling access to replaceable components without detachment from the machine or disturbance of adjacent equipment. This configuration aligns with expectations for in-situ maintenance of machine-mounted electrical equipment [12].

Cable routing is treated as a volumetric requirement rather than a predefined path. Internal space is reserved for slack management and strain relief, acknowledging variability in harness stiffness, connector geometry, and assembly practice.

4.3 Internal Layout, Clearances And Airflow Logic

The internal layout establishes orientations and clearances that support thermal behavior and mechanical accessibility without committing to quantified performance at this stage. Vertical motherboard orientation supports buoyancy-assisted airflow tendencies commonly assumed in compact computing enclosures [24], while the spatial arrangement of major heat sources defines a directional airflow intent.

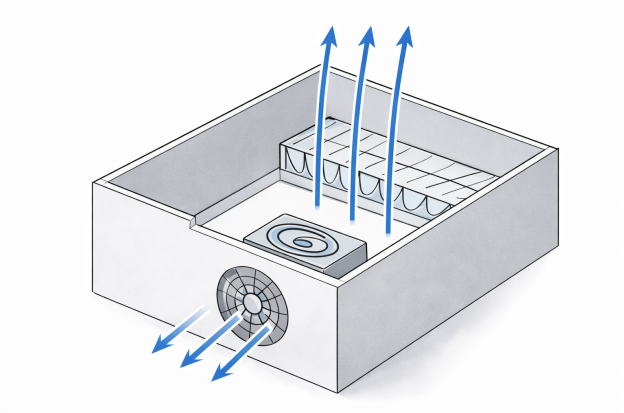


Figure 4.2: Internal Layout with Airflow Intent

Air exchange is distributed across multiple enclosure surfaces. The front face is defined as the primary exhaust-intended surface under nominal operation, aligned with the CPU cooling subsystem and front-panel vent pattern. Supplementary venting is incorporated on upper and lateral regions to provide pressure relief and additional flow paths for localized heat sources such as the graphics card. Openings are differentiated in geometry and

placement according to functional intent rather than treated as uniform perforations.

Clearances between components, vents, and enclosure walls are defined to preserve airflow continuity and avoid localized obstruction. At this architectural stage, airflow is treated as a directional system; quantitative evaluation of velocity fields and pressure distribution is deferred to subsequent engineering assessment.

4.4 Interface Definition And Assembly Constraints

Interface definition is central to maintaining architectural coherence across assembly, installation, and maintenance stages. The rear DIN-rail interface constitutes the primary mechanical boundary between the device and the machine and is realized via a dedicated bracket mounted to the enclosure body. This configuration preserves separation between mounting interface and internal component architecture.

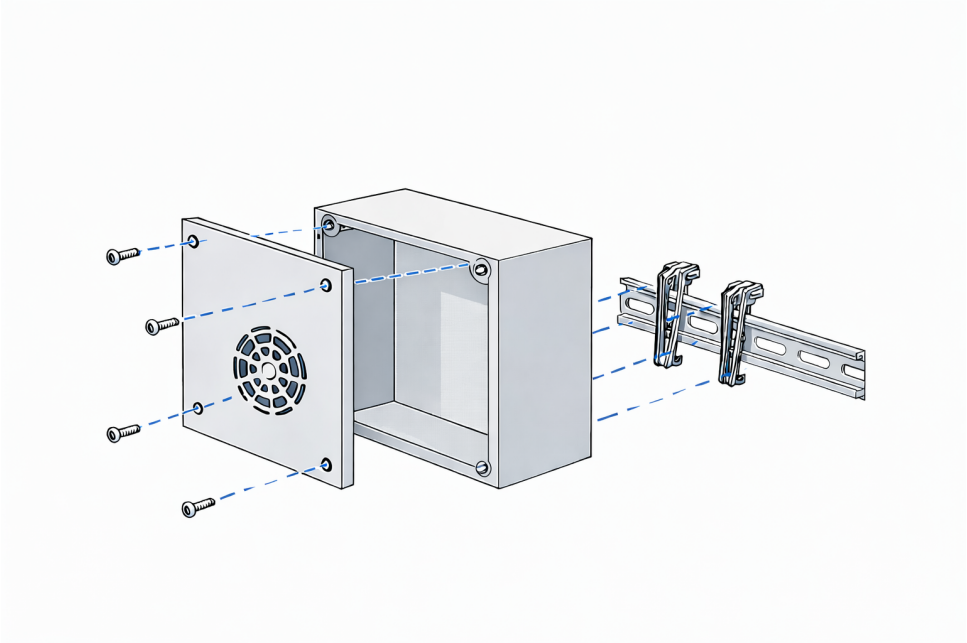


Figure 4.3: Interface and Assembly Logic Diagram

The front panel serves as the principal humandevice interface, mediating both service access and environmental separation. It is realized as a removable plate seated against a precision-machined perimeter interface. This establishes a controlled interface between the internal volume and the surrounding environment without implying full enclosure sealing.

Fastening strategies prioritize repeatability and accessibility. Major sub-assemblies are retained using standardized screwed connections with defined bearing surfaces, enabling disassembly without specialized tools while preserving preload under operational conditions. Internal mounting features such as bosses, ribs, and standoffs are integrated into the enclosure body to support component positioning and load transfer.

By defining system architecture, spatial relationships, and interface logic prior to external form generation, this chapter establishes a stable internal order that constrains subsequent formal development and prevents geometry from becoming arbitrary.

05

Formal Development Driven by Constraints

This chapter develops enclosure geometry directly from internal architecture, structural load paths, thermal logic, and subtractive manufacturing limits. It resolves non-prismatic form and vent articulation as consequences of constraint-led formal generation.

Chapter 5

Formal Development Driven By Constraints

5.1 Geometric Boundaries Defined By Internal Constraints

Formal development proceeds from the internal system architecture rather than from an externally imposed envelope. Component dimensions, clearance requirements, mounting interfaces, and defined service access zones collectively establish the geometric limits of the enclosure. Instead of compressing the internal system to fit a preconceived form, the enclosure expands and contracts locally in response to component envelopes, interface depths, airflow allowances, and assembly requirements.

This approach establishes a hierarchy in which internal necessity precedes external articulation. Wall thicknesses, offsets, and local volumes are non-uniform, increasing where structural support, fastening engagement, or interface accommodation is required and receding where no functional demand exists. The resulting geometry is intentionally non-prismatic, reflecting heterogeneous internal demands rather than an abstract volumetric ideal. Such constraint-led form development is consistent with manufacturing-oriented design methodologies in which geometry emerges from process, assembly, and use conditions rather than stylistic predefinition [25, 26].

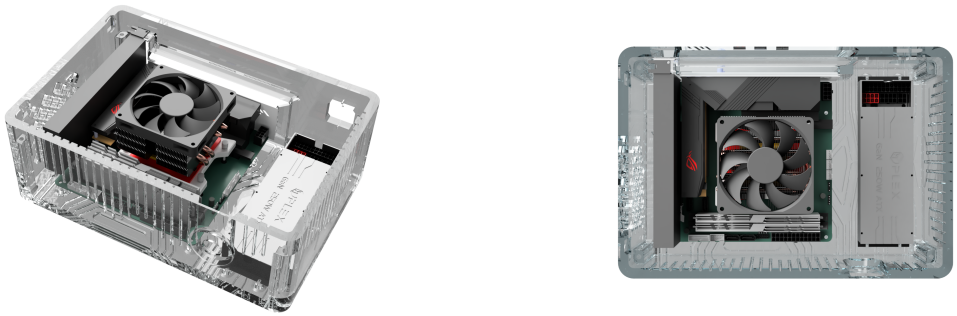


Figure 5.1: Geometric Envelope Emerging from Internal Constraints.

5.2 Structural And Thermal Phenomena As Formal Drivers

Structural and thermal considerations act as primary form drivers rather than downstream verification topics. Regions subjected to concentrated mechanical loadsmounting interfaces, fastener locations, and installation boundariesare locally thickened to establish continuous load paths and reduce stress concentrations. This strategy favors material continuity over thin secondary ribs, improving stiffness, vibration resistance, and long-term preload stability in machined aluminium structures [25].

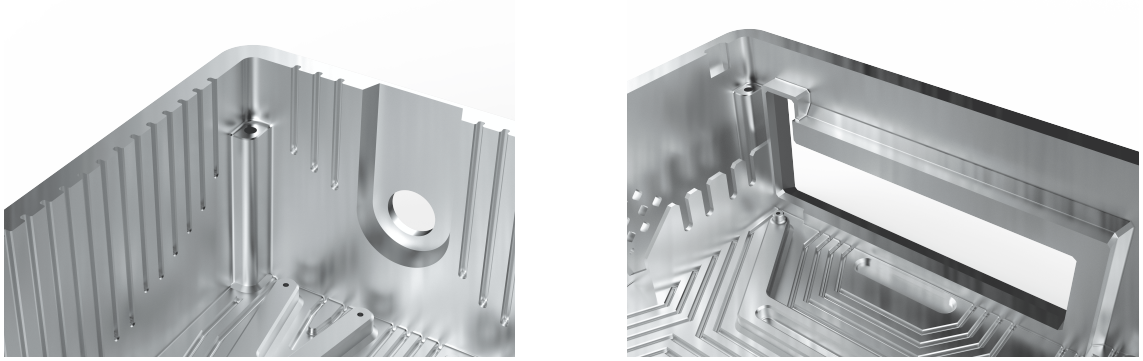


Figure 5.2: Structural Considerations in Stress-Prone Areas.

From a thermal perspective, the enclosure is conceived as a conductive mass capable of spreading and buffering internally generated heat rather than as a dedicated external heatsink. Internal channel networks are introduced within the enclosure base as a controlled material-removal strategy. These channels increase internal surface area while preserving structural continuity, supporting more uniform heat distribution and secondary convection without excessive geometric fragility [27].

Raised mounting blocks for the motherboard and power supply establish defined assembly reference planes while enabling conductive coupling between heat-generating components and the aluminium body. Structural support, thermal spreading, and assembly definition are therefore resolved through shared geometric features, reinforcing architectural coherence and reducing reliance on additive subsystems.

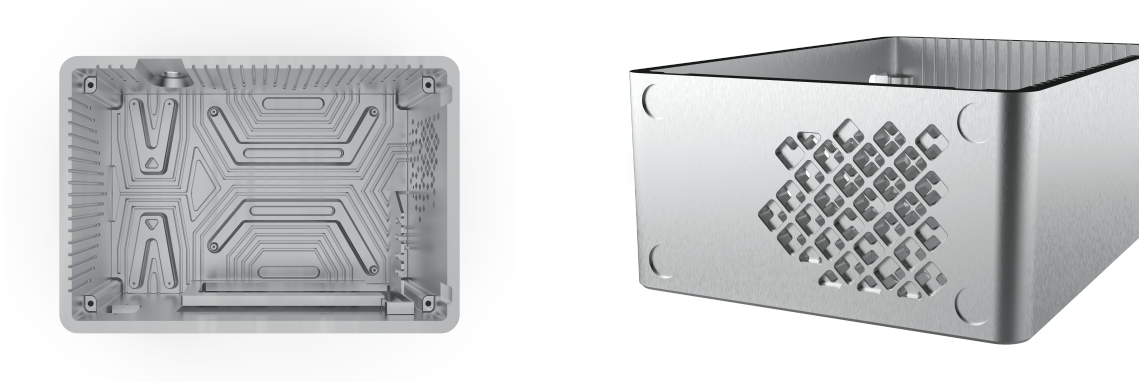


Figure 5.3: Internal Channel Network and Heat Distribution Strategy.

5.3 Manufacturing Constraints Influencing Geometry

Manufacturing conditions are treated as boundary constraints embedded directly into formal development. Internal corners are defined with radii compatible with rotating cutting tools, ensuring machinability within standard CNC milling processes and avoiding undercut geometries that complicate access or compromise surface quality [28]. As visible in Figures 5.2 and 5.3, both thickened structural regions and internal channel terminations are resolved using tool-compatible radii, preserving accessibility while maintaining load-path continuity and geometric stability. Vent apertures, pockets, and cutouts deliberately avoid sharp internal transitions that would require excessive tool overhang.

Feature proportions are controlled to avoid slender geometries susceptible to chatter during machining or damage during handling and assembly. Where edge definition is required, controlled chamfers act as deliberate edge breaks, improving deburring reliability and assembly safety. External filleting is selectively applied, allowing planar surfaces to remain explicit where curvature does not provide structural or manufacturing benefit [25, 26].

Fastener interfaces are integrated into locally thickened corner volumes supported by adjacent enclosure walls. This configuration accommodates standardized fasteners without excessive thread depth or thin surrounding material, promoting reliable preload retention under vibration. Fastener access directions and tool clearances are considered concurrently with geometry definition, preventing conflicts during assembly and service.

5.4 External Form, Vent Placement, And Functional Readability

External form emerges from internal constraints, structural logic, and defined manufacturing conditions rather than from independent styling intent. Vent placement is derived from the spatial alignment of internal heat sources instead of external symmetry. The front-panel ventilation field is intentionally offset to correspond with the position of the primary CPU cooling subsystem, reinforcing the precedence of internal architecture over formal balance.

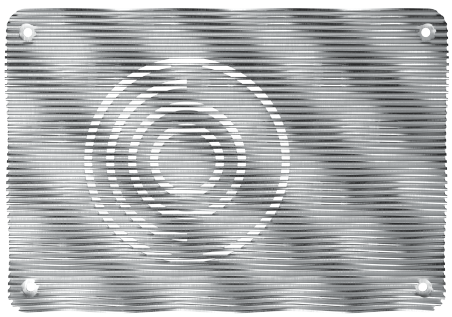


Figure 5.4: Vent Placement Derived from Internal Heat Alignment.

A continuous wave-modulated fin pattern is employed on the front panel in place of a rectilinear grille. This geometry avoids long, uninterrupted straight fins that could introduce vibration-sensitive slender features. Geometry modulation distributes stiffness across the panel while maintaining continuity at fin roots. Research on machining dynamics indicates that modulated tool paths and non-periodic geometries can reduce chatter sensitivity and improve process stability during milling operations [27].

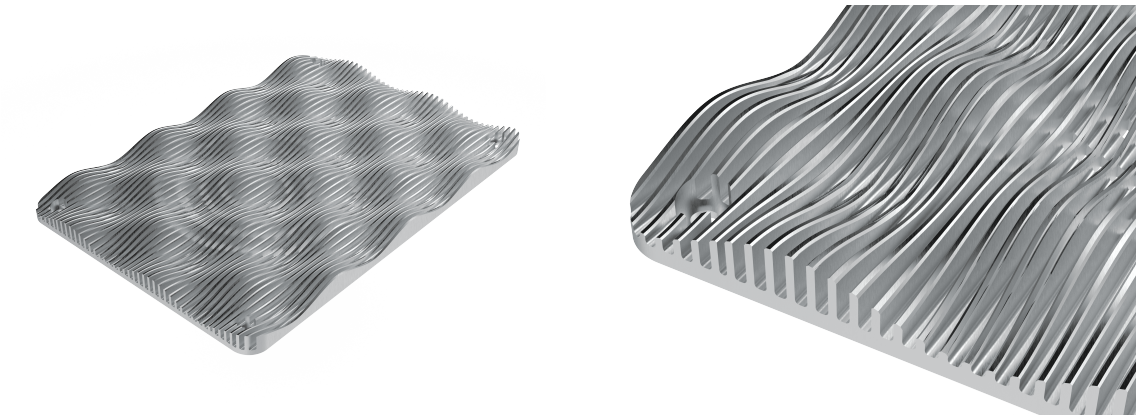


Figure 5.5: Wave-Modulated Surface Logic and Fin Root Continuity.

To prevent incorrect assembly arising from intentional asymmetry, a passive poka-yoke feature is integrated into the front-panel interface. Asymmetric locating geometry enforces a single valid assembly orientation, eliminating reliance on procedural control [26]. Fastening is achieved through countersunk screws seated in precision countersinks, preserving a flush external surface while enabling straightforward disassembly.

Through this constraint-driven process, external articulation is resolved rather than applied. Geometry communicates function, installation logic, and production awareness simultaneously, ensuring that the artefact remains legible and physically credible within its intended industrial context.

06

Design Synthesis and Architectural Coherence

This chapter synthesizes architectural, structural, and manufacturing decisions into a coherent enclosure identity. It confirms alignment between mass distribution, airflow organisation, machining legibility, and installation logic as an integrated system.

Chapter 6

Design Synthesis And Architectural Coherence

6.1 Role Of Synthesis Within The Design Process

This chapter consolidates the architectural, formal, and design-language outcomes of the enclosure development described in the preceding chapters. Rather than introducing new design actions or analytical results, it performs a synthesis of resolved decisions, clarifying how architectural intent, manufacturing logic, and functional constraints converge into a coherent whole.

The purpose of this synthesis is twofold:

- To demonstrate internal consistency between system architecture, formal development, and contextual requirements, and
- To establish a clear baseline against which subsequent engineering verification and manufacturing feasibility assessments can be meaningfully interpreted.

Design synthesis is therefore treated not as stylistic commentary, but as an evaluative step confirming that the enclosure operates as a unified architectural artefact rather than an accumulation of isolated solutions. If structural logic, airflow intent, manufacturing constraints, and installation requirements reinforce one another under this reading, the architecture demonstrates maturity. If not, it remains incomplete.



Figure 6.1: Final Enclosure Hero View (Installed Orientation).

6.2 Architectural Reading Of The Primary Enclosure Body

6.2.1 Formal Positioning And Mass Distribution

The lower enclosure volume defines the architectural foundation of the device. Its geometry is intentionally restrained, grounded, and proportionally stable, establishing both structural continuity and visual anchoring for the overall assembly.

Rather than pursuing visual lightness through aggressive thinning or stylistic reduction, compactness is achieved through disciplined proportion and controlled volumetric definition. Material concentration corresponds directly to structural necessity: mass is retained where load transfer, fastening engagement, and installation coupling demand continuity, and relieved where no mechanical function requires it.

This formal positioning aligns with the enclosures operational role. As a machine-integrated artefact exposed to vibration, thermal loading, and industrial handling, it requires uninterrupted load paths and stiffness continuity. The enclosure therefore reads as a single structural body rather than as an assembly of thin panels. In a vibration-prone environment, such continuity is not aesthetic preference but architectural responsibility.

The resulting presence is stable without exaggeration. The enclosure neither seeks visual dominance nor disguises its mass; it presents a controlled structural density appropriate to its context.

6.2.2 Machining Legibility As An Architectural Attribute

Manufacturing logic is deliberately expressed within the enclosure geometry. Tool accessibility, corner radii, surface continuity, and sectional transitions remain legible, reinforcing the understanding that the enclosure is generated through disciplined subtraction from a solid volume rather than through planar assembly.

Machining traces are treated as first-order architectural information rather than incidental residues. Section transitions are resolved through controlled curvature and proportion rather than through decorative detailing. Internal radii and transitional surfaces correspond to tool geometry and machining stability, embedding process constraints directly into form.

Generic chamfers are avoided in favour of deliberate edge definition and controlled curvature. The result is a form language that communicates precision and robustness without resorting to superficial ruggedisation or ornamental emphasis. Manufacturing discipline is therefore not concealed; it is integrated as part of the enclosures structural identity.

6.3 Synthesis Of The Top Panel And Ventilation Field

6.3.1 Architectural Role Of The Surface Modulation

The wave-modulated top panel represents the consolidation of architectural, functional, and manufacturing constraints. It is not an applied surface treatment but a volumetric condition emerging from airflow intent, stiffness continuity, and machining feasibility.



Figure 6.2: Top Panel Surface Modulation and Airflow Alignment comparing (a) Flat and (b) Modulated.

Without this surface logic, the enclosure remains functionally coherent but lacks fully resolved architectural articulation. The wave field introduces controlled directionality and continuity, allowing the enclosure to communicate orientation and airflow alignment without reliance on applied graphics or external markers.

The modulation is therefore inseparable from structural and thermal reasoning. It participates in airflow interaction, interrupts periodic structural behaviour that could arise from long straight fins, and preserves continuity at fin roots. Expression and function are not layered; they are integrated.

6.3.2 Transition From Surface Articulation To Volumetric Logic

Initially explored as a surface articulation, the wave geometry evolved into a volumetric feature as airflow strategy, structural continuity, and machining constraints converged. This evolution was not driven by aesthetic escalation but by alignment of independent requirements.

In its resolved form, the wave field participates simultaneously in:

- Airflow organisation and vent interaction,
- Modulation of local stiffness and wall continuity,
- Perceptual scaling of the enclosure volume, and
- Visual orientation within its installation context.

The surface therefore cannot be treated as an independent layer. It is structurally and functionally embedded within the enclosure body.

6.3.3 Parametric Consistency And Perceptual Complexity

All wave elements derive from a single parametric definition. Complexity emerges through orientation, cropping, and continuity rather than through multiplicity of gestures or variation of motif.

This decision preserves manufacturing clarity and geometric discipline while avoiding decorative redundancy. The wave field reads as a segment of a continuous underlying system rather than as a closed or arbitrary composition. The enclosure is therefore governed by internal order rather than surface composition.

6.4 Hierarchy Of Faces And Directional Legibility

The enclosure establishes a deliberate hierarchy between its faces:

- The wave-modulated surface functions as the primary directional and communicative plane,
- Secondary faces prioritise infrastructural clarity, accommodating ventilation, mounting interfaces, and access features.

As observable in Figures 6.1 and 6.2, the modulation of the primary surface establishes visual orientation, while adjacent faces remain restrained and functionally explicit.

This separation prevents expressive articulation from interfering with functional clarity. Vent openings, mounting features, and interface cut-outs remain legible without competing for emphasis.

Coherence is achieved not through symmetry, but through alignment with airflow direction, component orientation, and gravitational logic. Orientation is communicated implicitly through geometry rather than through applied markings. As a result, the enclosure belongs to its installation context rather than appearing placed upon it.

6.5 Design Language Positioning

6.5.1 Industrial Character Without Exaggeration

The design language is intentionally industrial while avoiding both heavy-handed ruggedisation and consumer-oriented minimalism. The enclosure does not attempt to appear indestructible, nor does it pursue visual lightness inappropriate to its operational demands.

Instead, it occupies a position characterised by precision, restraint, and structural confidence. Mass distribution, surface control, and geometric continuity signal durability without exaggeration. This positioning allows the enclosure to exist credibly within industrial machinery while maintaining a distinct architectural identity.

6.5.2 Reduction Through Responsibility

Formal reduction is employed as a discipline rather than as an aesthetic shortcut. Every retained feature carries structural, thermal, manufacturing, or architectural responsibility.

Surfaces are preserved only where they contribute to load continuity, airflow management, assembly logic, or directional clarity. Subtlety arises through proportional control and

alignment rather than stylistic emphasis. The enclosure avoids neutrality by ensuring that each geometric decision remains traceable to constraint.

6.6 Iterative Consolidation And Design Maturity

The resolved configuration represents progressive consolidation rather than replacement-driven iteration. Earlier design states explored partial resolutions of structural continuity, surface modulation, and proportional balance. Over successive refinements, independent elements aligned under a consistent architectural logic.

No feature is present as an isolated gesture. Each reflects refinement of a shared underlying intent shaped by constraint. The enclosure therefore reads as developed rather than assembled, its maturity arising from convergence between requirement and form.

6.7 Temporal Robustness And Design Longevity

The enclosure references established industrial artefact logic through proportional discipline and exposed functional clarity without direct imitation. The intent is continuity with industrial precedent rather than stylistic quotation.

By avoiding transient stylistic cues and trend-driven detailing, the geometry is positioned for long-term relevance within evolving technological contexts. Durability is understood not as visual neutrality, but as persistence of architectural logic under changing operational and manufacturing conditions.

6.8 Synthesis Outcome

The enclosure architecture achieves alignment between structural continuity, thermal responsibility, manufacturing discipline, and installation logic within a compact machine-mounted volume. It communicates precision without fragility and presence without excess.

Its identity emerges from coherence: the integration of mass distribution, airflow strategy, machining constraint, and geometric restraint into a single continuous system.

This synthesis establishes a stable architectural baseline against which subsequent engineering verification, manufacturing evaluation, and lifecycle considerations can be conducted with clarity and methodological consistency.

07

Manufacturing and Assembly as Physical Boundary Conditions

This chapter positions five-axis CNC machining, geometric accessibility, and targeted tolerancing as boundary conditions preserving architectural continuity. It ensures monolithic structural integrity and interface stability remain physically manufacturable.

Chapter 7

Manufacturing and Assembly as Physical Boundary Conditions



Figure 7.1: Exploded Assembly Overview

7.1 Position of Manufacturing Within the Investigation

Manufacturing and assembly are not treated here as domains of process optimisation or production strategy. They function instead as physical boundary conditions that determine whether the resolved enclosure architecture can exist as a credible, repeatable artefact.

By the conclusion of Chapter 6, the enclosure geometry and internal organisation are architecturally fixed. The role of this chapter is therefore not to reshape the design, but to examine the conditions under which the defined configuration can be realised without violating structural continuity, interface logic, or thermal intent. Manufacturing operates as a plausibility filter: if the geometry cannot be produced under realistic industrial conditions, the architectural claim would be weakened.

7.2 Monolithic Realisation and Architectural Continuity

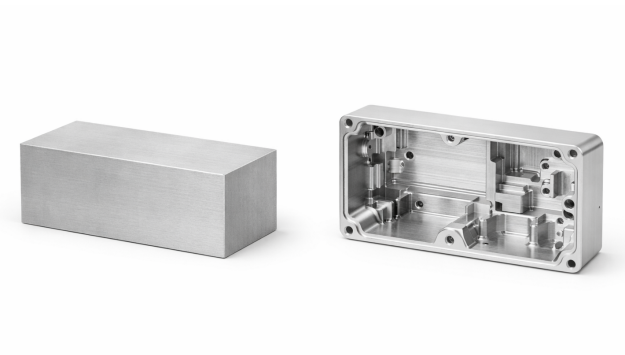


Figure 7.2: Monolithic Machining Strategy (Billet and Machined Body)

The enclosure body is maintained as a single primary structural component. This decision is not positioned as an exploration of manufacturing capability, but as a condition required to preserve load-path continuity, local wall thickening, and integrated mounting features established in earlier chapters.

Under conventional three-axis machining constraints, the non-prismatic internal cavities and multi-directional features would necessitate segmentation into multiple joined parts. Such segmentation would introduce additional fasteners, alignment tolerances, and contact interfaces, fundamentally altering structural and thermal behaviour [27, 29]. To avoid these discontinuities, a five-axis CNC milling environment is treated as the enabling boundary condition under which the architecture remains intact.

Alternative constructionssuch as folded sheet-metal assemblies or bonded sub-componentsare acknowledged as viable in other contexts. Within the present architectural framework, however, such approaches would impose planar logic and restrict local material continuity required for vibration resistance and integrated fastening volumes [26, 30]. Manufacturing therefore preserves architectural coherence rather than driving geometric reinvention.

Standardised mounting elements, including the DIN rail interface, remain discrete purchased components. This separation prevents standard profiles from distorting the enclosure body and maintains clarity between architectural volume and installation hardware.

7.3 Geometric Accessibility and Machining Stability

Manufacturability constrains geometry primarily through tool accessibility and local feature stability. Internal cavities, mounting bosses, and interface regions are configured to remain accessible within conventional five-axis tool orientations without reliance on undercuts or specialised cutters [25].

Sharp internal corners and slender unsupported geometries are avoided where they would introduce tool chatter, excessive overhang, or compromised surface quality. Where machining limits are approached, local material is retained to preserve rigidity during cutting operations rather than reducing global section thickness [25, 31].

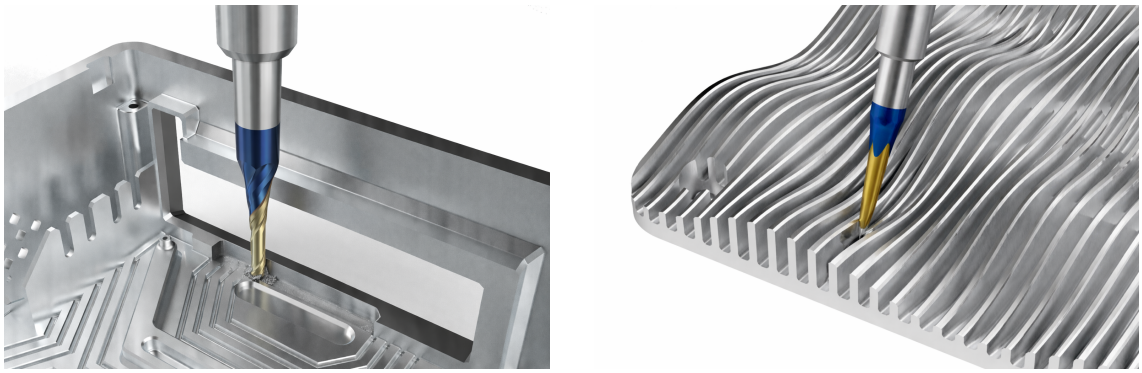


Figure 7.3: Tool Accessibility and Setup Orientation

Multiple machining setups and re-clamping operations are accepted as procedural realities. Single-setup completion is not imposed as a governing constraint, as doing so would require geometric simplifications incompatible with internal organisation. In this context, additional setups represent manufacturing effort rather than architectural compromise.

Manufacturing thus refines geometry through stabilisation rather than simplification.

7.4 Interface Precision and Targeted Tolerance Strategy

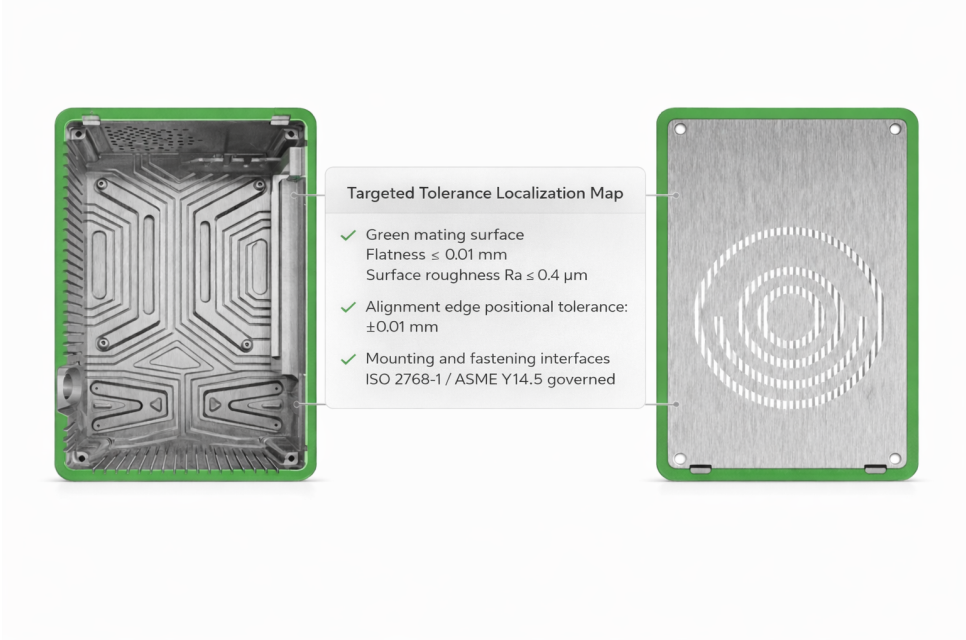


Figure 7.4: Targeted Tolerance Localization Map

Dimensional precision is applied selectively. Tight tolerances are localised to interfaces where deviation would directly affect load transfer, fastening integrity, or enclosure closure. These include threaded features, mounting interfaces, and mating surfaces governing panel alignment [32, 33].

Elsewhere, tolerances are intentionally relaxed. Internal clearance volumes, routing spaces, and non-contact surfaces accommodate manufacturing variability and thermal expansion

without functional consequence. This targeted application preserves repeatability while avoiding unnecessary sensitivity to production variation.

Precision is therefore treated as a functional boundary condition rather than a global aesthetic requirement.

7.5 Manufacturing as Validation Anchor

The manufacturing and assembly conditions established in this chapter do not modify the enclosure architecture. They delimit the domain within which subsequent material assumptions, simulation studies, and reliability assessments remain meaningful.

By ensuring that monolithicity, feature accessibility, and interface stability are achievable under realistic subtractive manufacturing conditions, the investigation avoids evaluating an idealised geometry detached from production reality [27, 26].

Manufacturing is therefore not positioned as a subject of innovation within this thesis. It acts as a stabilising constraint that anchors the design-led architectural development in physical feasibility.

08

Declared Material Assumptions and Architectural Boundary Conditions

This chapter fixes Aluminium 7075 as a declared material constant to stabilise structural, thermal, and assembly reasoning across the enclosure. It frames material not as an optimisation outcome but as a boundary condition reinforcing load-path continuity, heat spreading, and machinability.

Chapter 8

Declared Material Assumptions And Architectural Boundary Conditions

8.1 Position Of Material Within The Investigation

Material selection is not developed here as a comparative optimisation study. It is fixed as a boundary condition that stabilises architectural, geometric, and manufacturing reasoning. Once enclosure form, structural continuity, and assembly logic are resolved, material properties provide the physical constants against which mechanical and thermal behaviour can be interpreted consistently [34, 35].

This chapter is therefore declarative. A single material system is explicitly adopted and carried forward into subsequent mechanical and thermal assessments. The objective is internal coherence rather than performance maximisation.

8.2 Operating Context And Material Demands

From a manufacturing standpoint, the monolithic milling strategy requires a material compatible with stable cutting behaviour, predictable tool engagement, and controlled surface quality without reliance on bonded or welded secondary operations [25, 31].

8.3 Declared Reference Material: Aluminium Alloy 7075

The alloys high specific stiffness and strength enable compact wall sections, integrated threaded bosses, and locally thickened structural regions without excessive mass [36, 37]. These characteristics support the monolithic enclosure strategy and the continuity of load paths required for vibration-exposed, machine-adjacent deployment.

Its thermal conductivity supports distributed heat spreading within the enclosure body, complementing the airflow logic established in earlier chapters [36]. The material therefore

reinforces the architectural intent of a thermally aware structural mass rather than a thin protective shell.

Machinability of 7075 in common heat-treated states (e.g., T6 or T651) supports precise realisation of internal cavities, controlled radii, and consistent surface transitions under multi-axis CNC milling [25, 31, 38]. The heat-treatment condition is assumed fixed and is not treated as a variable within this thesis.

8.4 Surface Condition And Environmental Stability

Surface treatments such as anodising are acknowledged as beneficial for corrosion resistance and long-term surface stability in environments with elevated humidity or chemical exposure [39, 40]. However, they are treated as conditional enhancements rather than defining features of the architectural baseline.

8.5 Architectural Implications Of The Material Assumption

Predictable elastic behaviour supports reliable fastener preload retention at enclosure interfaces under vibration and service loading [29]. Thermal expansion characteristics remain compatible with the scale of internal components and fastening strategy, avoiding extreme differential expansion effects.

Material definition is therefore not presented as an independent design achievement. It functions as a physical constant that allows the resolved enclosure architecture to be evaluated coherently within its intended industrial context.

09

Validation Stance and Analytical Scope

This chapter defines validation as a plausibility-oriented interpretive exercise rather than optimisation or certification. It establishes modelling assumptions, analytical limits, and the central role of engineering judgement in assessing structural and thermal coherence under fixed constraints.

Chapter 9

Validation Stance And Analytical Scope

9.1 Purpose Of Validation Within A Constraint-Driven Framework



Figure 9.1: Validation Framework: Boundary Conditions Engineering Judgement

Validation in this thesis is not positioned as performance optimisation, regulatory certification, or probabilistic lifetime prediction. It functions as an interpretive engineering exercise aimed at assessing whether the fixed enclosure configuration behaves in a physically plausible and internally consistent manner under representative industrial conditions.

The enclosure architecture, material system, manufacturing strategy, and installation logic established in preceding chapters are treated as non-negotiable boundary conditions.

Validation therefore evaluates the consequences of these fixed decisions rather than revisiting or optimising them. The objective is to exclude structurally adverse behaviour, identify inconsistencies between assumptions and outcomes, and confirm that the configuration demonstrates reasonable robustness within its intended deployment context.

This stance reflects common industrial practice during constraint-driven development phases, where engineering analysis informs judgement under limited iteration freedom and incomplete operational data rather than serving as exhaustive numerical proof.

9.2 Central Role Of Engineering Judgement

Engineering judgement governs interpretation of all analytical results presented in this thesis. Numerical simulation and structured reasoning tools are treated as instruments supporting evaluation, not as autonomous arbiters of correctness.

Model simplifications in material behaviour, boundary conditions, load representation, and environmental assumptions are explicit and intentional. Consequently, simulation outputs are interpreted as indicators of deformation trends, stress distribution patterns, airflow organisation, and sensitivity to configuration changes rather than as absolute predictors of real-world performance.

Judgement is exercised to determine whether:

- Observed behaviours align with physical intuition,
- Load transfer paths remain coherent,
- Local stress concentrations are structurally reasonable,
- Airflow patterns correspond to architectural intent,
- No gross inconsistencies undermine the design premise.

Quantitative outputs are therefore contextualised within architectural reasoning rather than evaluated against isolated numerical thresholds.

9.3 Analytical Tools And Their Deliberate Scope

Analytical methods are selected according to their suitability for plausibility assessment under fixed constraints.

Structural numerical analysis is employed to evaluate deformation magnitudes, load-path continuity, and stress distribution under representative installation, handling, and operational loading scenarios. The purpose is to detect excessive compliance, unrealistic stress localisation, or discontinuities incompatible with the intended structural behaviour. Fatigue life prediction, shock response simulation, and certification-level strength verification are outside the defined scope.

Computational airflow and thermal analysis are applied to examine ventilation organisation, pressure distribution tendencies, and heat-spreading behaviour under simplified thermal loading assumptions. These studies verify coherence of airflow intent and thermal interaction between components and enclosure mass, without claiming precise temperature prediction or regulatory compliance.

Structured failure reasoning informed by DFMEA principles is used qualitatively to identify critical interfaces and potential failure modes. Formal risk-priority scoring and compliance-driven documentation procedures are intentionally excluded to maintain focus on architectural robustness rather than documentation completeness.

Each tool is therefore bounded by a clearly defined purpose aligned with the thesis stance.

9.4 Modelling Assumptions And Declared Limits

All validation activities are conducted under explicit modelling assumptions. These include linear elastic material behaviour, static or quasi-static representative loads, simplified contact definitions, and idealised constraint representations.

Environmental effects are represented through bounding scenarios rather than stochastic or probabilistic models. Vibration exposure is addressed through structural continuity assessment and representative loading conditions rather than full dynamic frequency-response simulation, except where modal tendencies are examined at a first-order level.

Manufacturing variability, assembly tolerances, and long-term material degradation are considered qualitatively at interface level but are not modelled statistically. These simplifications are consistent with the stated objective of plausibility verification and avoid implying predictive certainty beyond the thesis scope.

9.5 Scope Of Applicability

The validation conclusions derived in subsequent chapters apply strictly to the evaluated enclosure configuration under the declared assumptions and representative operating conditions.

They do not constitute certification evidence, lifetime guarantees, or compliance statements. The findings are not transferable to configurations involving significant geometric modification, alternative material systems, different installation strategies, or substantially altered environmental exposure.

The validation approach presented here is intended to demonstrate disciplined engineering reasoning within a constraint-defined architectural framework, not to replace formal qualification testing or regulatory verification procedures.

9.6 Closing Statement

This chapter establishes the interpretive framework governing all subsequent analytical results. By defining the limits, assumptions, and role of engineering judgement, the thesis positions simulation and structured reasoning as instruments for assessing physical plausibility under constraint.

Validation is therefore presented not as proof of optimisation, but as disciplined confirmation that the resolved enclosure architecture remains coherent when subjected to representative mechanical and thermal realities.

10

Engineering Observation of Architectural Behaviour

This chapter presents structural, modal, airflow, and thermal observations of the fixed enclosure configuration under representative loading conditions. It confirms volumetric stiffness, coherent load transfer, stable airflow topology, and bounded thermal behaviour within declared modelling limits.

Chapter 10

Engineering Observation Of Architectural Behaviour

10.1 Structural Behaviour Under Representative Mechanical Conditions

The enclosure architecture defined in Chapter 5 emerges from internal organisation, installation constraints, and subtractive manufacturability. Once geometrically resolved and materially fixed (Aluminium 7075-T6), its mechanical behaviour under gravity-dominated deployment conditions is examined.

Simulation is employed strictly as an observational instrument. Geometry, wall thickness distribution, vent definition, mounting interfaces, and material properties are treated as fixed outcomes. No geometric refinement or optimisation is introduced in response to numerical results.

10.1.1 Model Definition And Assumptions

The structural model is derived directly from the resolved enclosure geometry. All load-bearing walls, ribs, mounting bosses, and thickness transitions are preserved. Minor cosmetic fillets are suppressed only where necessary to improve solver robustness without altering first-order stiffness behaviour.

- Material properties Aluminium 7075-T6 (linear elastic assumption):
- Youngs modulus: 71 GPa
- Poissons ratio: 0.33
- Yield strength: 500 MPa
- Density: 2810 kg/mş

Mounting interfaces corresponding to machine attachment points are modelled as fully fixed translational constraints (Ux = Uy = Uz = 0), representing rigid coupling to

the host structure. This assumption slightly reduces predicted global displacement and conservatively transfers reaction stresses into mounting regions.

Gravitational acceleration of 9.807 m/sš is applied globally.

Second-order solid elements with curvature-aware meshing are used. Average element size corresponds to approximately 34% of the enclosure envelope dimension, preserving first-order stiffness characteristics while maintaining computational tractability.

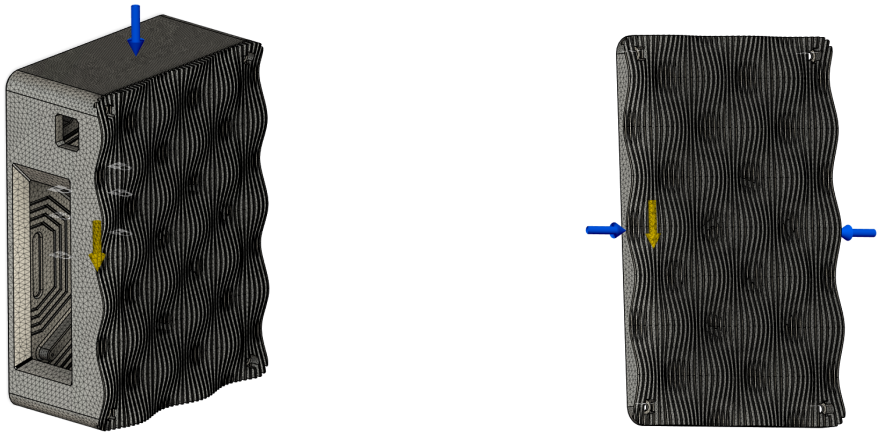


Figure 10.1: Structural Model Definition: Boundary Conditions and Load Application for Static Assessment.

10.1.2 Load Case A Self-Weight In Installed Configuration

Global gravitational acceleration is applied to the enclosure mass (approximately 56 kg).

Observed behaviour:

- Global deformation remains small relative to enclosure dimensions.
- Stress distribution is smooth and continuous.
- No local amplification appears at mounting interfaces.
- Side walls and mounting bosses act as primary load-transfer members.
- The enclosure behaves as a closed-section structural body rather than as independent plate elements.

This response confirms that mass distribution and wall continuity produce coherent load paths under installed self-weight.

10.1.3 Load Case B Fully Assembled Configuration

Additional distributed mass representing internal electronics is introduced at internal support locations.

Observed behaviour:

- Moderate stress increase near internal mounting regions.
- No torsional instability or asymmetric distortion.
- Load transfer remains coherent from upper surfaces toward mounting anchors.
- Internal component mass does not introduce destabilising eccentricity.
- The enclosure retains structural hierarchy, with internal masses coupling predictably into the primary load path.

10.1.4 Load Case C Handling-Induced Top Loading

A uniform downward load is applied across the top panel while mounting interfaces remain constrained, approximating handling or installation conditions generating cantilever-type bending.

The induced bending moment is approximated by:

$M = F \cdot d$

where F represents the applied force and d the vertical offset between the load plane and the mounting centroid.

Observed behaviour:

- Stress gradients remain distributed rather than localised.
- No yield-adjacent regions emerge.
- Maximum displacement remains small relative to assembly tolerances.
- The enclosure exhibits torsion-resistant behaviour characteristic of monolithic closed geometry.

Across all static load cases, no excessive compliance or stress concentration incompatible with machine-adjacent deployment is observed.

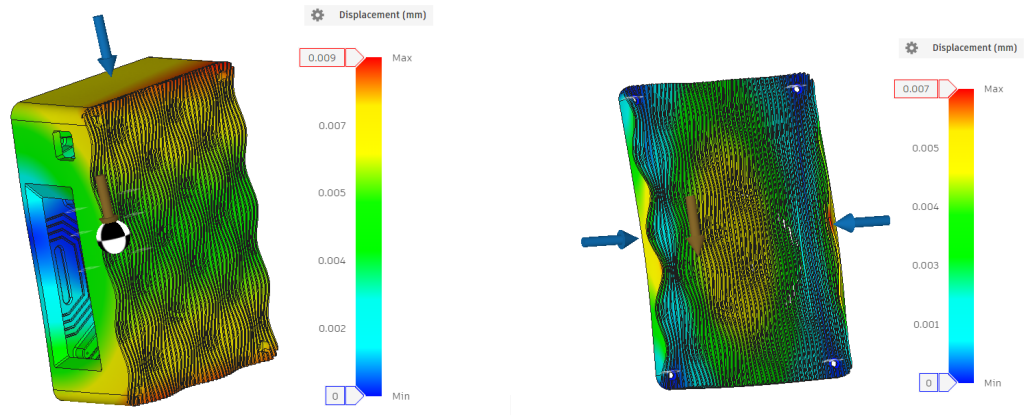


Figure 10.2: Top Loading of Fully Assembled Configuration and Local Panel Bending

10.2 Modal Characterisation Of Global Stiffness

To observe inherent stiffness distribution and structural hierarchy, a linear free-vibration modal analysis is conducted under installed boundary conditions.

The first global natural frequency appears above approximately 150 Hz. The first several modes exhibit distributed bending and torsional behaviour rather than isolated panel flutter. No low-frequency (<100 Hz) global structural mode is detected.

The absence of low-frequency global modes, combined with limited static deflection under bending-dominated loading, indicates that stiffness is distributed volumetrically rather than concentrated in thin plate elements.

Modal results are interpreted descriptively and do not constitute vibration certification or resonance avoidance analysis.

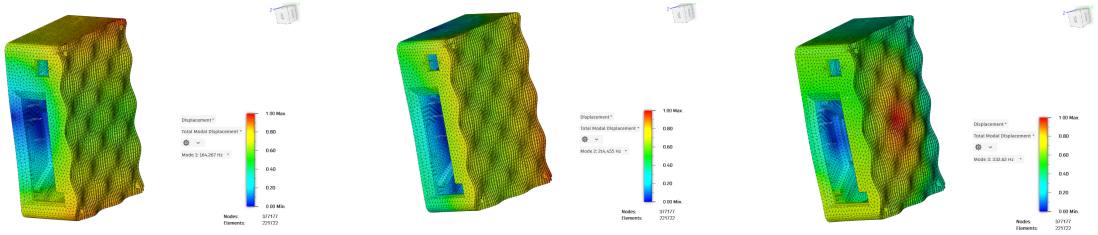


Figure 10.3: First three natural modes of the enclosure under fixed mounting constraints: 164.3 Hz, 214.5 Hz, and 332.6 Hz. Deformation visually amplified.

10.3 Airflow And Thermal Behaviour As Architectural Consequence

Airflow behaviour is examined as a continuation of architectural reasoning. The objective is not thermal optimisation but observation of whether the defined vent geometry and spatial organisation support coherent forced convection under representative internal heat generation.

10.3.1 Component Definition And Boundary Conditions

The computational model incorporates commercially defined components:

- AMD Ryzen 9 7900 processor (dominant heat source)
- ASUS ROG Strix B650E-I Mini-ITX motherboard
- Noctua NH-L9x65 cooling assembly (33 CFM nominal airflow)
- NVIDIA A1000 single-slot GPU (3.5 CFM secondary airflow)
- HDPLEX 250 W passive GaN power supply

Auxiliary electronics are represented as consolidated distributed motherboard heat.

Ambient temperature is fixed at 25 řC.

Two internal heat conditions are evaluated:

Representative operating load

Elevated internal heat input of approximately 204 W

Fans are modelled at constant nominal volumetric flow rates. Observed static pressure differentials remain on the order of approximately 2540 Pa, placing operation within the near-linear region of small axial fan performance curves. For enclosure-level architectural interpretation, constant-CFM modelling is therefore acceptable.

Gravity is included to allow buoyancy effects to emerge naturally.

10.3.2 Behaviour Under Representative Thermal Load

Internal air velocities predominantly range between approximately 0.5 m/s and 45 m/s, with peak magnitudes near the primary fan discharge.

Observed behaviour:

- Air enters and exits exclusively through defined vent geometries.
- Vent openings demonstrate active pressure coupling with the internal domain.
- Flow redistributes longitudinally across the enclosure cavity.
- Local recirculation zones remain dynamically coupled to primary flow paths.
- No enclosure-wide stagnation regions are observed.

Thermally, elevated temperatures remain localised near dominant heat sources and decay progressively along established airflow paths. No global thermal saturation occurs.

10.3.3 Behaviour Under Elevated Internal Heat ($\approx 204\,\mathrm{W}$)

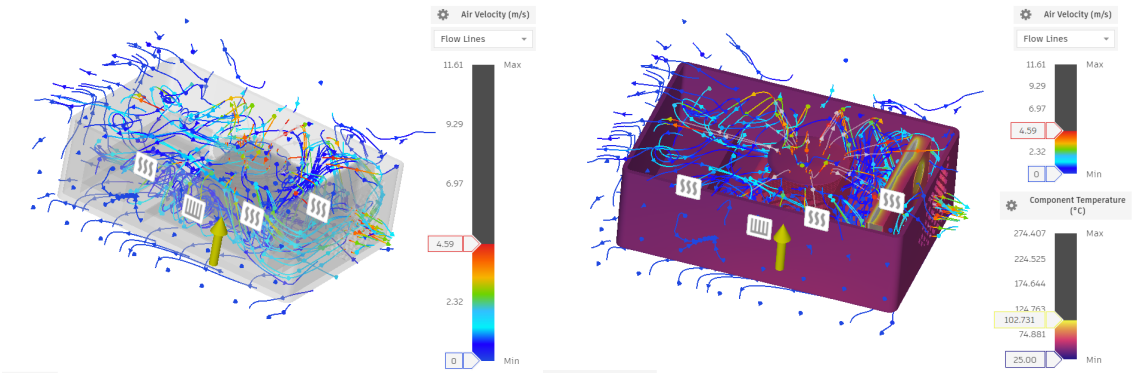


Figure 10.4: Volumetric airflow and temperature distribution under elevated internal heat input ($\approx 204\,\mathrm{W}$).

Under elevated thermal loading:

- Velocity magnitudes remain within the same order of magnitude.
- Pressure differentials increase modestly but remain bounded.
- Convective transport remains dominant over buoyancy.
- No chimney-dominated transition is observed.
- No vent sealing or pressure trapping occurs.

Temperature gradients steepen near dominant sources, and certain regions exhibit higher local thermal concentration. These zones represent architectural sensitivity areas rather than systemic failure.

The fundamental airflow topology remains stable under increased heat input.

10.4 Interpretive Boundaries

The analyses presented:

- Do not evaluate fatigue life
- Do not predict machine-induced vibration amplitudes
- Do not include impact loading
- Do not include full fan-curve modelling
- Do not simulate dust accumulation or leakage
- Do not constitute certification-level validation

Within these declared bounds, engineering analysis confirms that the enclosure architecture behaves in a mechanically and thermally coherent manner under representative deployment conditions.

Simulation therefore supports the architectural argument rather than redefining it.

11

Conclusion

This chapter reframes constraint as a generator of architectural clarity and reflects on the enclosure as a structurally continuous, thermally aware, manufacturable artefact. It positions the thesis contribution as methodological: a validation-oriented, constraint-driven approach to machine-integrated enclosure architecture.

Chapter 11

Conclusion

11.1 Reframing The Problem

This thesis began with a specific condition: the physical integration of a compute-scale industrial edge device directly within CNC machining environments. Unlike cabinet-contained electronics or low-power monitoring units, such deployment collapses conventional separation between computation and machine infrastructure. The enclosure is no longer a passive housing; it becomes a structural, thermal, and environmental mediator.

Rather than treating enclosure design as secondary packaging, this work positioned it as a primary architectural problem. Environmental exposure, DIN-rail installation, vibration presence, subtractive manufacturability, and predefined electronics were treated as fixed boundary conditions. Within these constraints, the central question was not how to optimise performance, but whether a coherent, physically credible architecture could be defined and evaluated without dissolving into compromise.

11.2 Constraint As Generator

A key methodological stance of this thesis is that constraint is not a limitation to be overcome, but a generator of architectural clarity.

By fixing:

- electronic configuration,
- installation interface,
- material system,
- manufacturing domain,
- and validation limits,

the design process was forced into resolution rather than iteration-driven adjustment. Form emerged as a consequence of load paths, thermal flow, machining accessibility, and service

logic. Geometry was not imposed; it was shaped by internal necessity.

This approach demonstrates that enclosure architecture, when treated seriously, becomes inseparable from structure, airflow organisation, and assembly reasoning. The resulting artefact is not a neutral shell but a continuous body whose mass distribution, vent topology, and interface definition operate as an integrated system.

11.3 Observed Behaviour Under Validation

Engineering observation confirmed that the resolved enclosure behaves coherently within representative mechanical and thermal conditions.

Under gravity-dominated loading and handling scenarios, deformation remains limited and load transfer continuous. The monolithic geometry distributes stress without isolated plate-like instability. Modal characterisation indicates volumetric stiffness rather than panel-dominated behaviour.

Airflow assessment shows that ventilation openings are not symbolic but active interfaces. Under both representative and elevated heat input, airflow topology remains stable, pressure differentials remain bounded, and convective transport remains dominant. Thermal concentration occurs locally near dominant sources, but systemic saturation or stagnation is not observed within the evaluated domain.

These observations do not constitute certification or lifetime prediction. They confirm plausibility: that the enclosure architecture does not contradict the physical realities it claims to address.

11.4 Architectural Identity

The final enclosure is grounded rather than expressive. Its personality emerges not from stylistic gesture but from alignment between structural continuity, thermal responsibility, and manufacturing legibility.

Mass is distributed where load paths demand it. Vent geometry aligns with airflow intent. Machining logic remains visible but disciplined. Installation hierarchy is embedded rather than applied. The wave-modulated surface participates simultaneously in airflow interaction, stiffness modulation, and directional articulation.

The enclosure does not attempt to appear indestructible. It appears resolved.

11.5 Contribution

The contribution of this thesis is methodological and architectural rather than technological.

It formalises a validation-oriented, constraint-driven approach to machine-integrated enclosure design in which:

- architecture is fixed before simulation,

- manufacturing acts as a boundary rather than a driver of compromise,
- material is declared to stabilise reasoning,
- and validation serves interpretation rather than optimisation.

Within this framework, engineering analysis becomes a tool for confirming coherence rather than redefining form.

This approach is particularly relevant for industrial hardware development contexts where time, iteration freedom, and ownership boundaries are constrained, yet architectural credibility must still be demonstrated.

11.6 Final Position

In machine-adjacent deployment, enclosure architecture must reconcile environmental exposure, vibration presence, thermal load, manufacturing realism, and service accessibility simultaneously. When these forces are treated explicitly and without hierarchy, form cannot remain arbitrary.

This thesis demonstrates that a disciplined, constraint-led process can yield an enclosure that is structurally continuous, thermally aware, manufacturable, and physically plausible under representative conditions.

The result is not a final product specification. It is a coherent architectural baseline one that stands quietly within its industrial context, supported by engineering observation and bounded by declared assumptions.

That is the resolution achieved.

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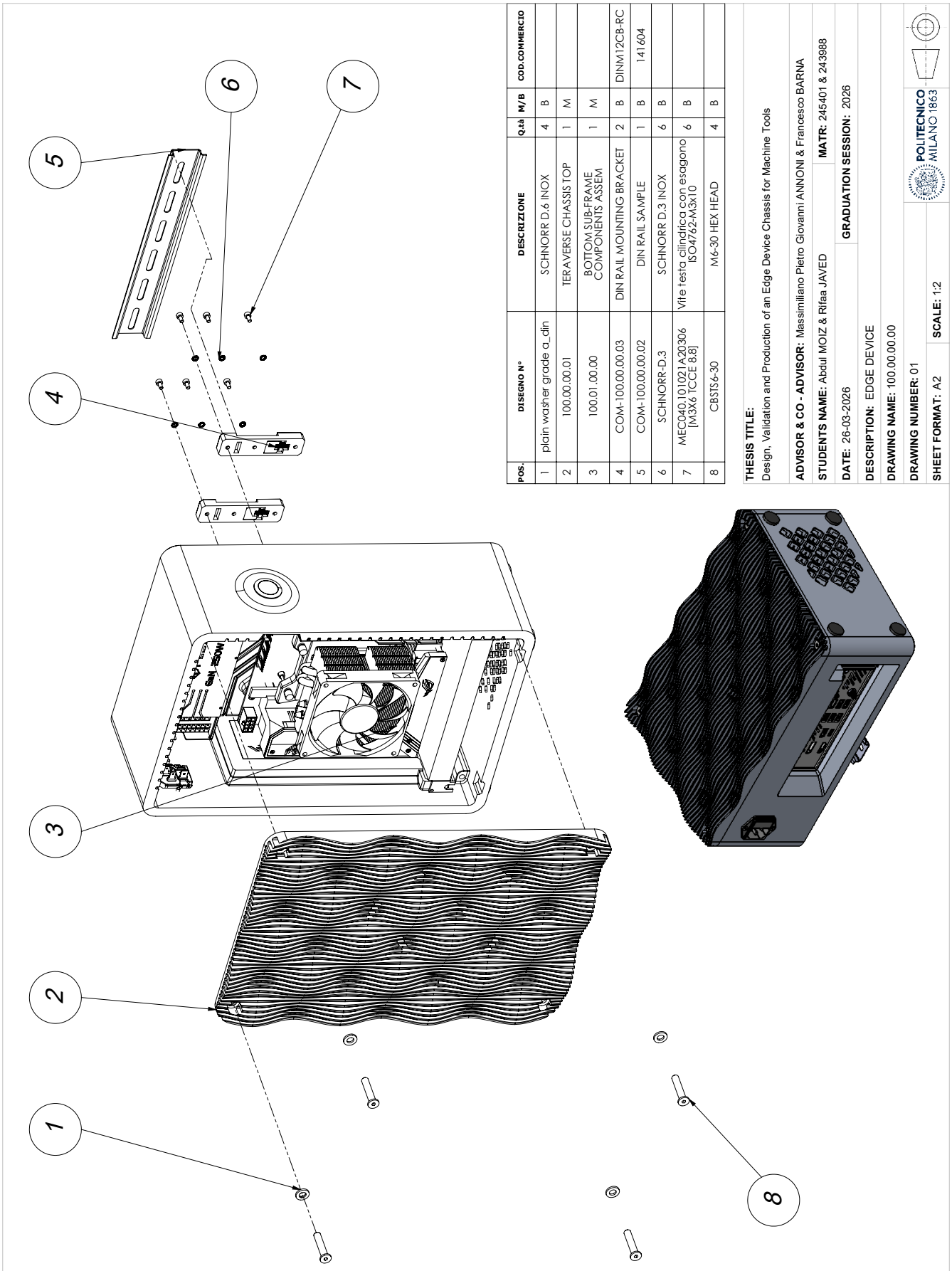
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Appendix A

Detailed Manufacturing Drawings

A.1 Edge Device



POS.	DISEGNO N°	DESCRIZIONE	Q.tà	M/B	COD.COMMERCIO
1	plain washer grade a_din	SCHNORR D.6 INOX	4	B	
2	100.00.00.01	TERAVERSE CHASSIS TOP	1	M	
3	100.01.00.00	BOTTOM SUB-FRAME COMPONENTS ASSEM	1	M	
4	COM-100.00.00.03	DIN RAIL MOUNTING BRACKET	2	B	DINM12CB-RC
5	COM-100.00.00.02	DIN RAIL SAMPLE	1	B	141604
6	SCHNORR-D.3	SCHNORR D.3 INOX	6	B	
7	MEC040.101021A20306 [M3X6 TCCE 8.8]	Vite testa cilindrica con esagono ISO4762-M3x10	6	B	
8	CBSTS6-30	M6-30 HEX HEAD	4	B	

THESIS TITLE:
Design, Validation and Production of an Edge Device Chassis for Machine Tools

ADVISOR & CO - ADVISOR: Massimiliano Pietro Giovanni ANNONI & Francesco BARNA

STUDENTS NAME: Abdul MOIZ & Rifaa JAVED **MATR:** 245401 & 243988

DATE: 26-03-2026 **GRADUATION SESSION:** 2026

DESCRIPTION: EDGE DEVICE

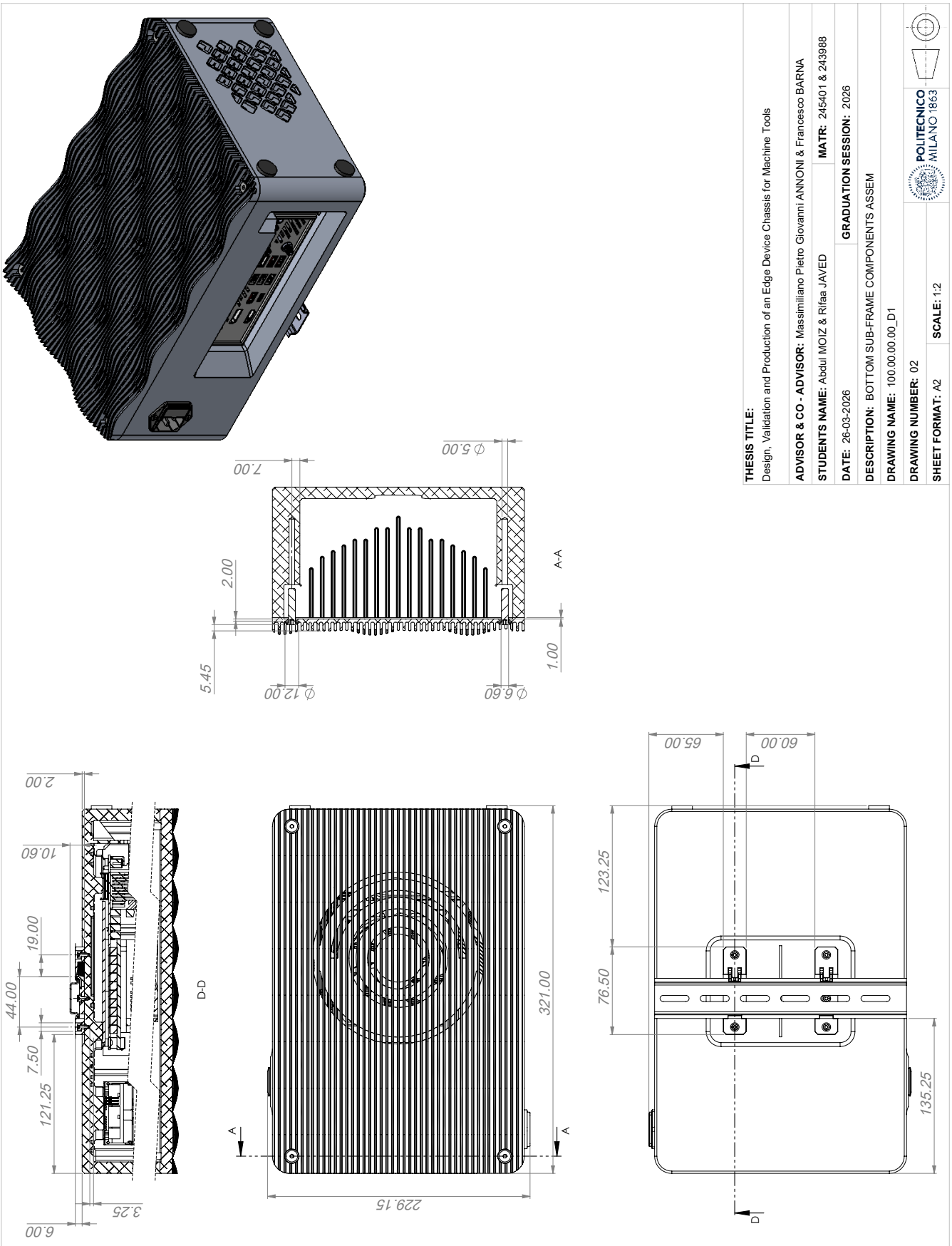
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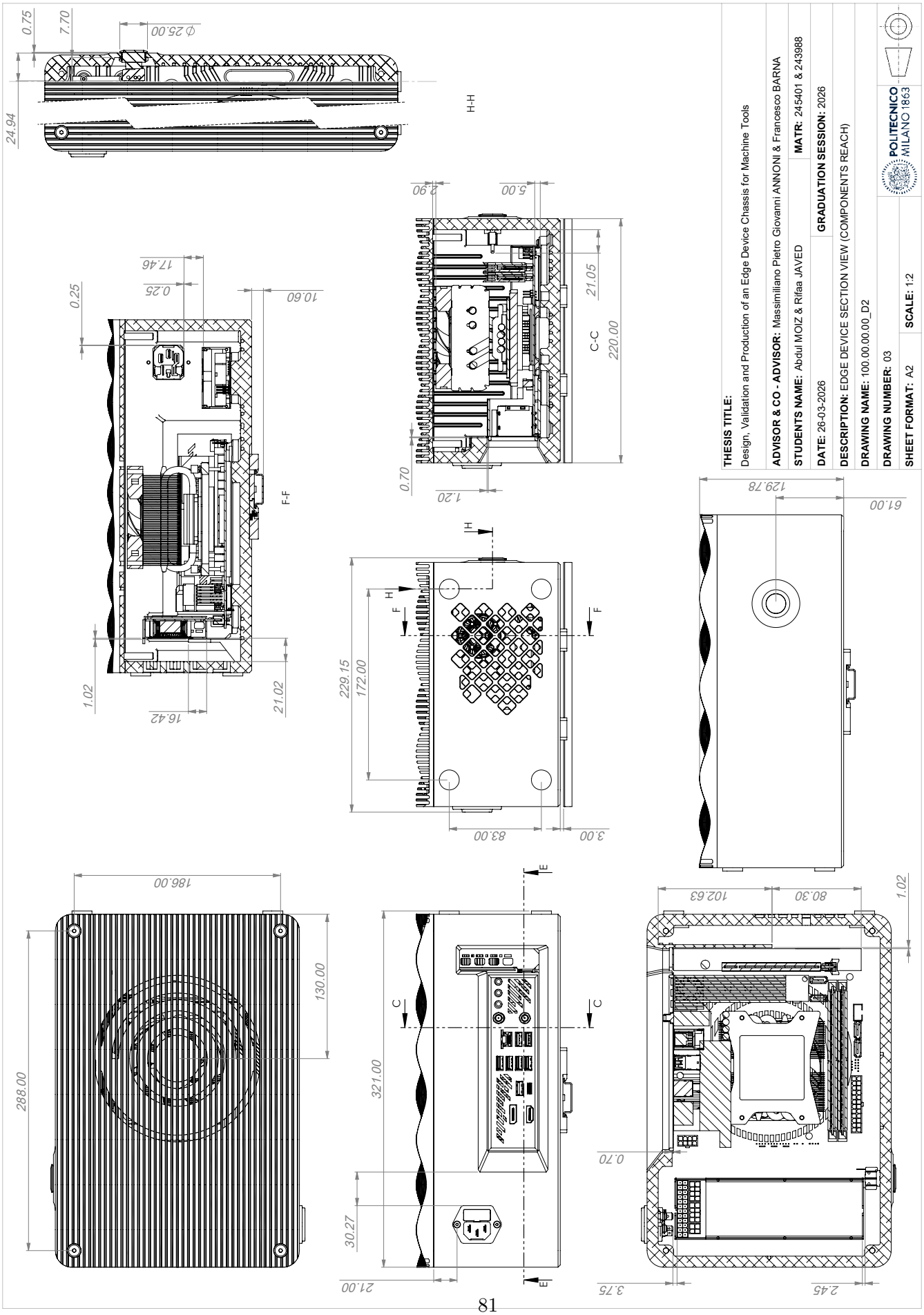
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POLITECNICO MILANO 1863

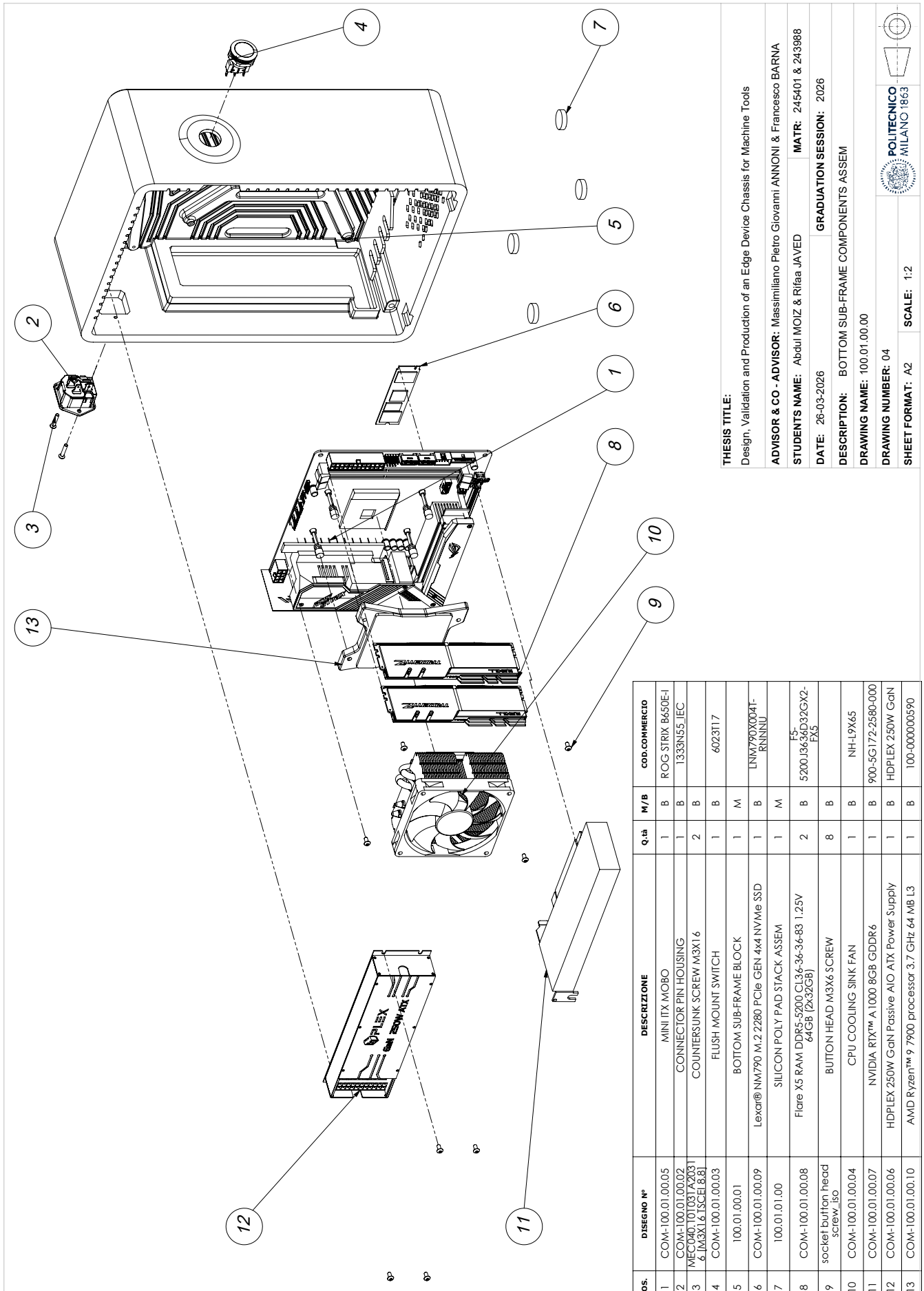
A.2 Bottom Sub-Frame Components Assembly



A.3 Edge Device Section View (Components Reach)



A.4 Bottom Sub-Frame Components Assembly



POS.	DISEGNO N°	DESCRIZIONE	Q.tà	M/B	COD.COMMERCIO
1	COM-100.01.00.05	MINI ITX MOBO	1	B	ROG STRIX B650E-I
2	COM-100.01.00.02	CONNECTOR PIN HOUSING	1	B	1333N55_IEC
3	MEC040.101031A2031 6_(M3X16 TSCEI 8.8)	COUNTERSUNK SCREW M3X16	2	B	
4	COM-100.01.00.03	FLUSH MOUNT SWITCH	1	B	6023117
5	100.01.00.01	BOTTOM SUB-FRAME BLOCK	1	M	
6	COM-100.01.00.09	Lexar® NM790 M.2 2280 PCIe GEN 4x4 NVMe SSD	1	B	LNM790X004T-RNNNU
7	100.01.01.00	SILICON POLY PAD STACK ASSEM	1	M	
8	COM-100.01.00.08	Flare X5 RAM DDR5-5200 CL36-36-36-83 1.25V 64GB (2x32GB)	2	B	F5-5200J3636D32GX2-FX5
9	socket button head screw_iso	BUTTON HEAD M3X6 SCREW	8	B	
10	COM-100.01.00.04	CPU COOLING SINK FAN	1	B	NH-L9X65
11	COM-100.01.00.07	NVIDIA RTX™ A1000 8GB GDDR6	1	B	900-5G172-2580-000
12	COM-100.01.00.06	HDPLEX 250W GaN Passive AIO ATX Power Supply	1	B	HDPLEX 250W GaN
13	COM-100.01.00.10	AMD Ryzen™ 9 7900 processor 3.7 GHz 64 MB L3	1	B	100-000000590

THESIS TITLE:
Design, Validation and Production of an Edge Device Chassis for Machine Tools

ADVISOR & CO - ADVISOR: Massimiliano Pietro Giovanni ANNONI & Francesco BARNA

STUDENTS NAME: Abdul MOIZ & Rifaa JAVED **MATR:** 245401 & 243988

DATE: 26-03-2026 **GRADUATION SESSION:** 2026

DESCRIPTION: BOTTOM SUB-FRAME COMPONENTS ASSEM

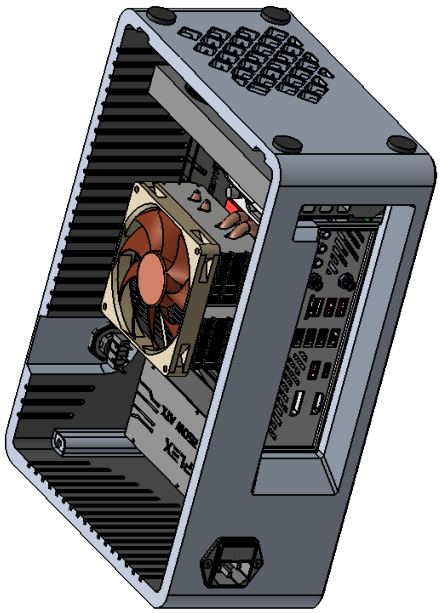
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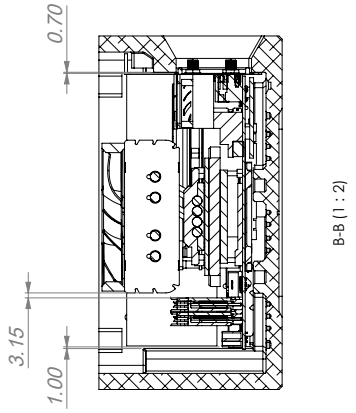
DRAWING NUMBER: 04 **SCALE:** 1:2

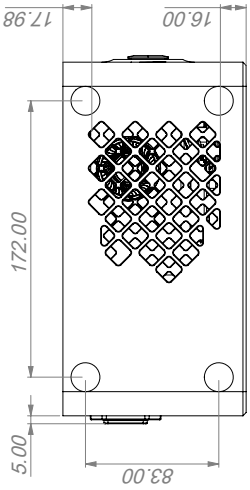
SHEET FORMAT: A2

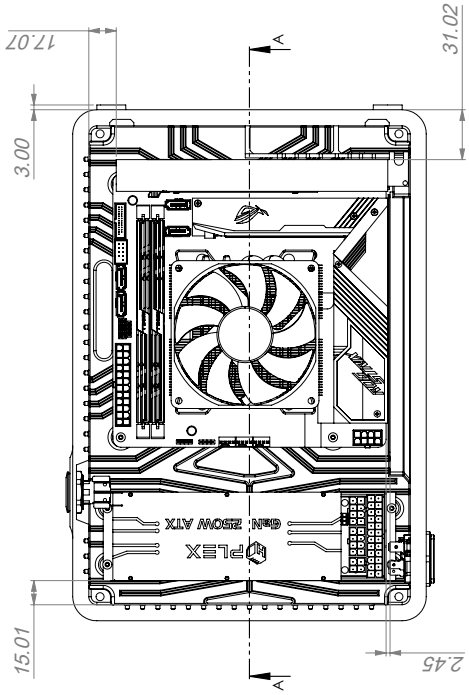
POLITECNICO MILANO 1863

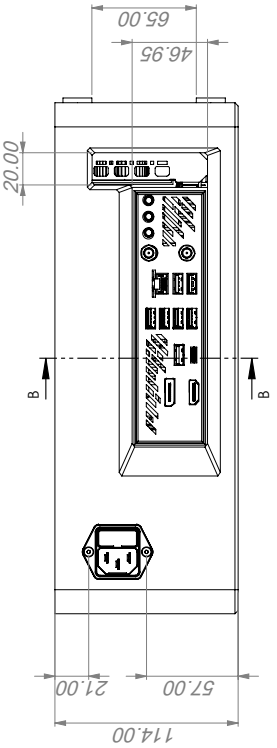
A.5 Bottom Sub-Frame Components Assembly Section View

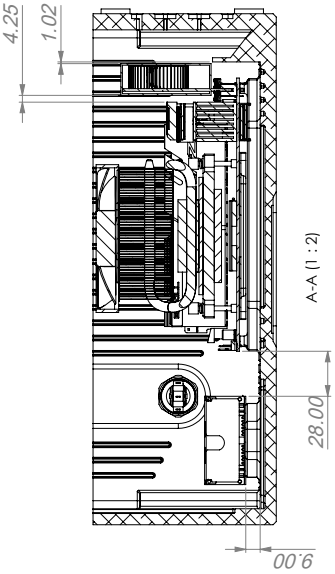






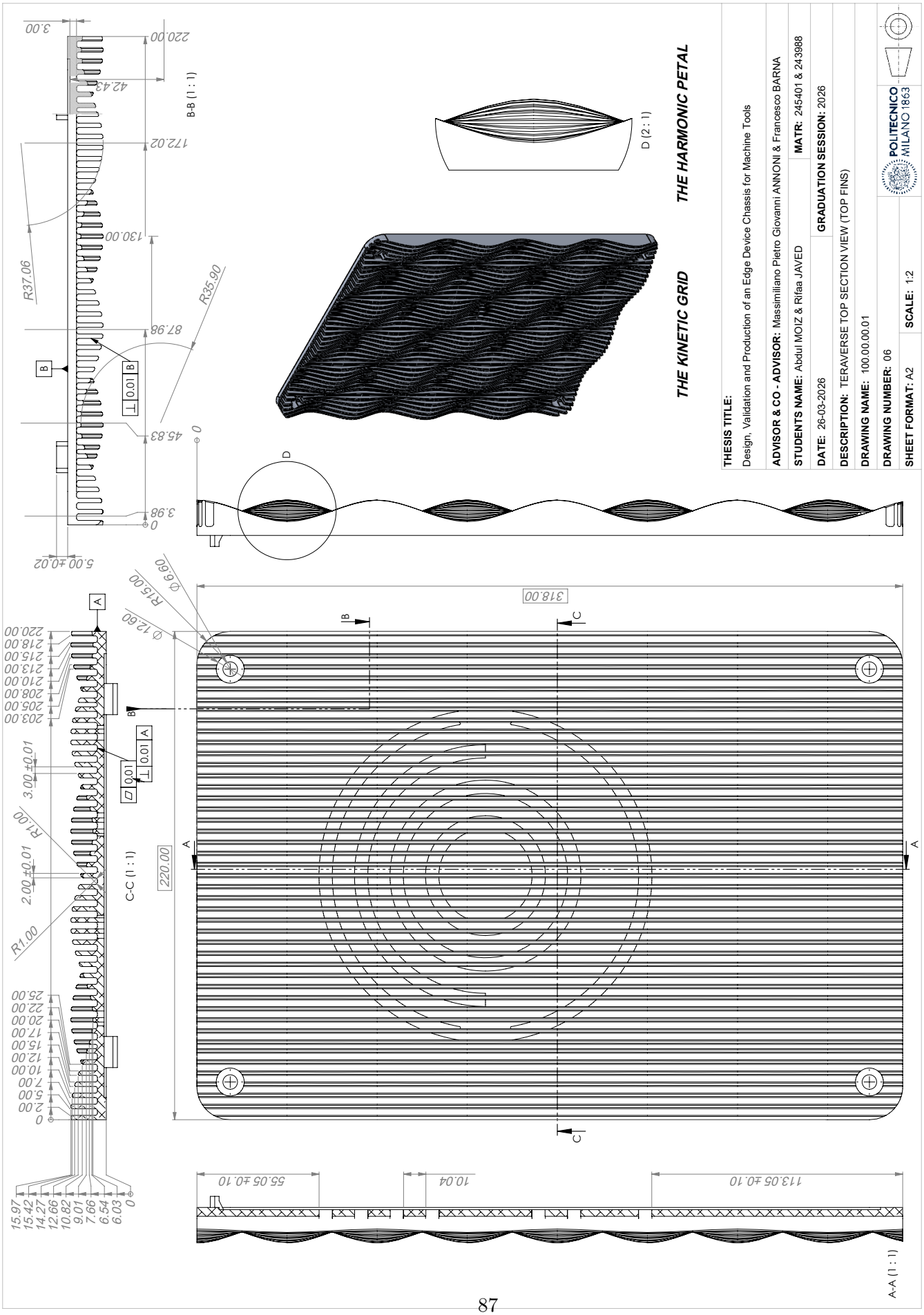




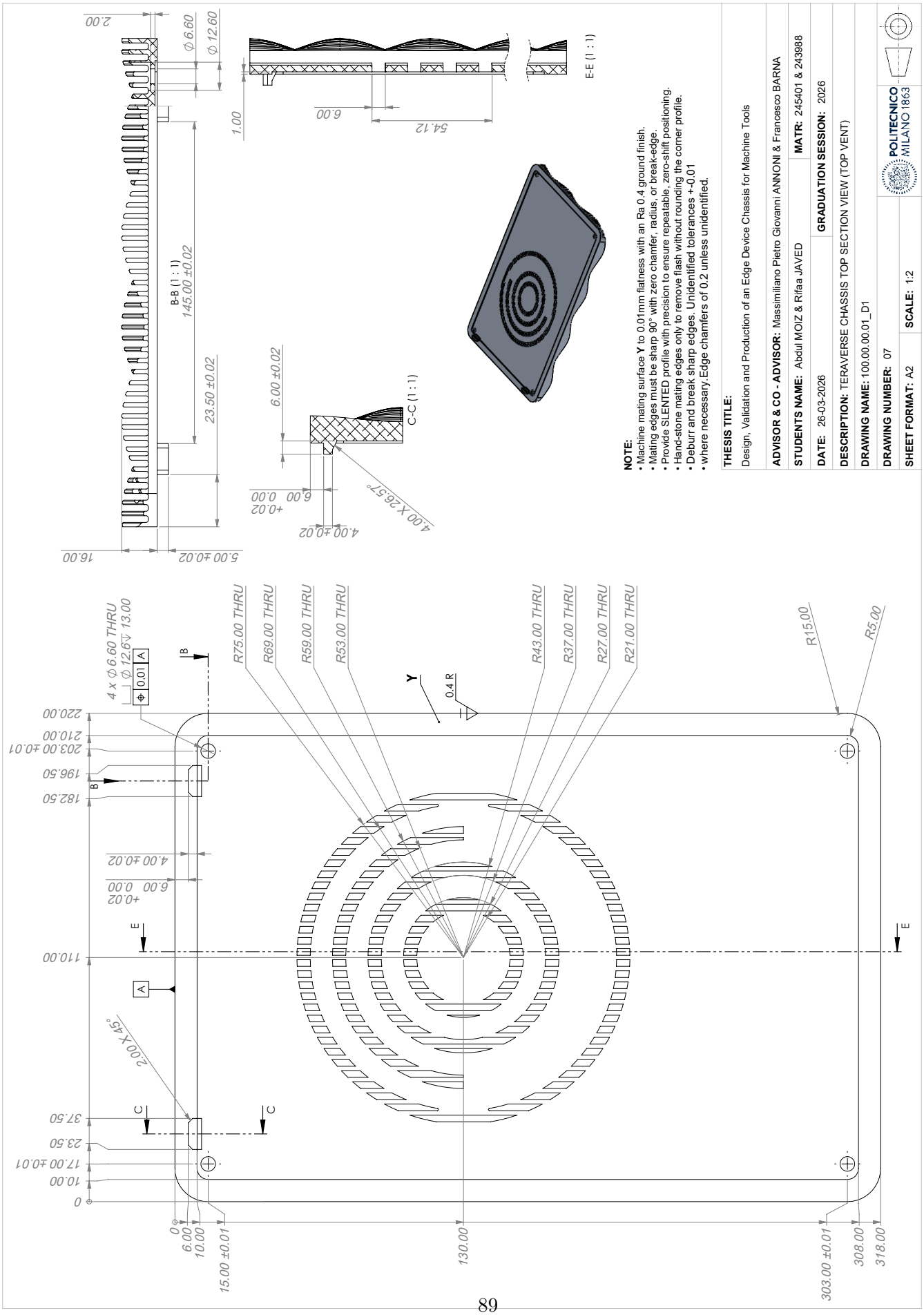


THESIS TITLE: Design, Validation and Production of an Edge Device Chassis for Machine Tools	
ADVISOR & CO - ADVISOR: Massimiliano Pietro Giovanni ANNONI & Francesco BARNA	
STUDENTS NAME: Abdul MOIZ & Rifaa JAVED	**MATR:** 245401 & 243988
DATE: 26-03-2026	**GRADUATION SESSION:** A2
DESCRIPTION: BOTTOM SUB-FRAME COMPONENTS ASSEM SECTION VIEW	
DRAWING NAME: 100.01.00.00_D1	
DRAWING NUMBER: 05	POLITECNICO MILANO 1863
SHEET FORMAT: A2	**SCALE:** 1:2

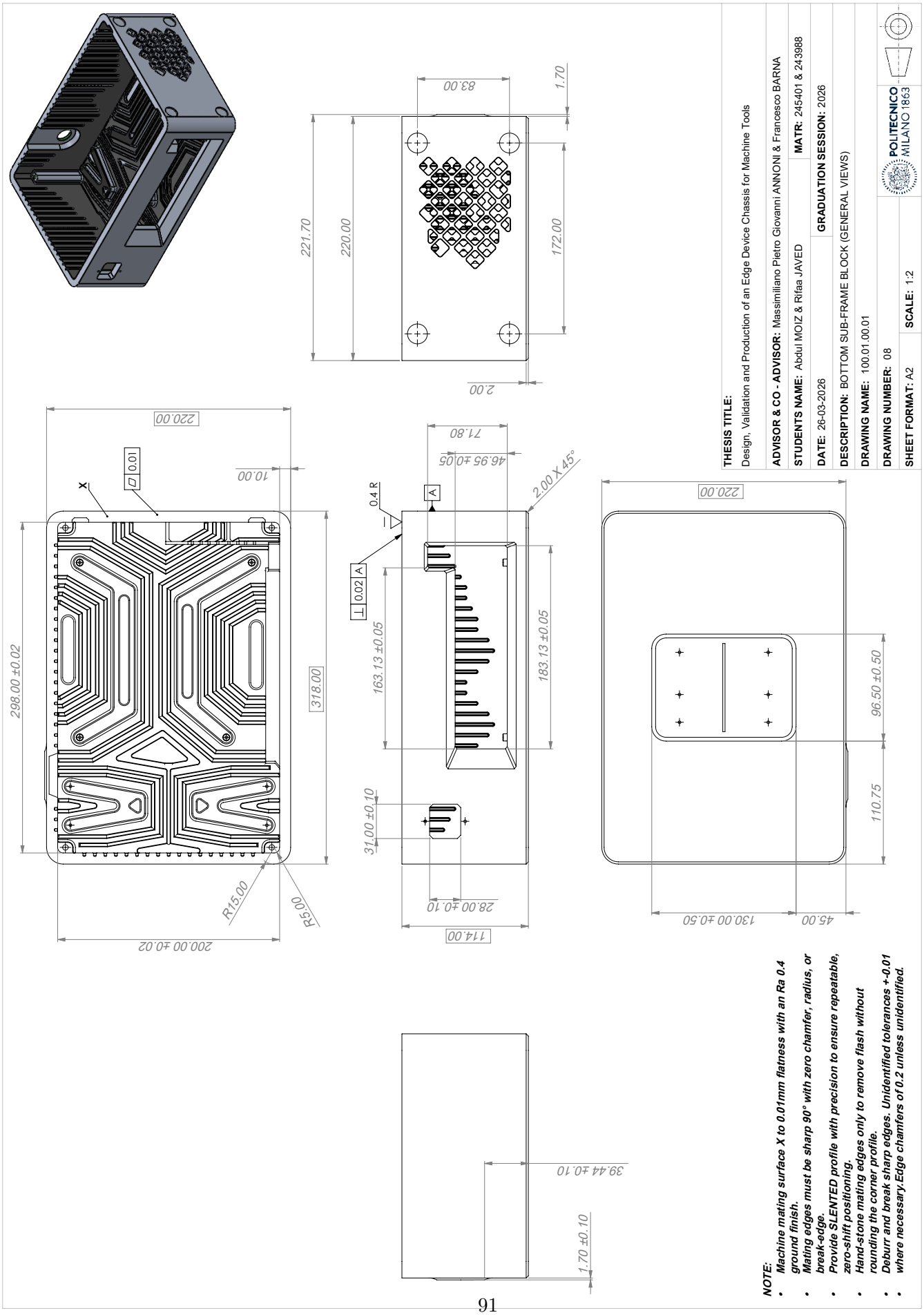
A.6 Teraverse Top Section View (Top Fins)



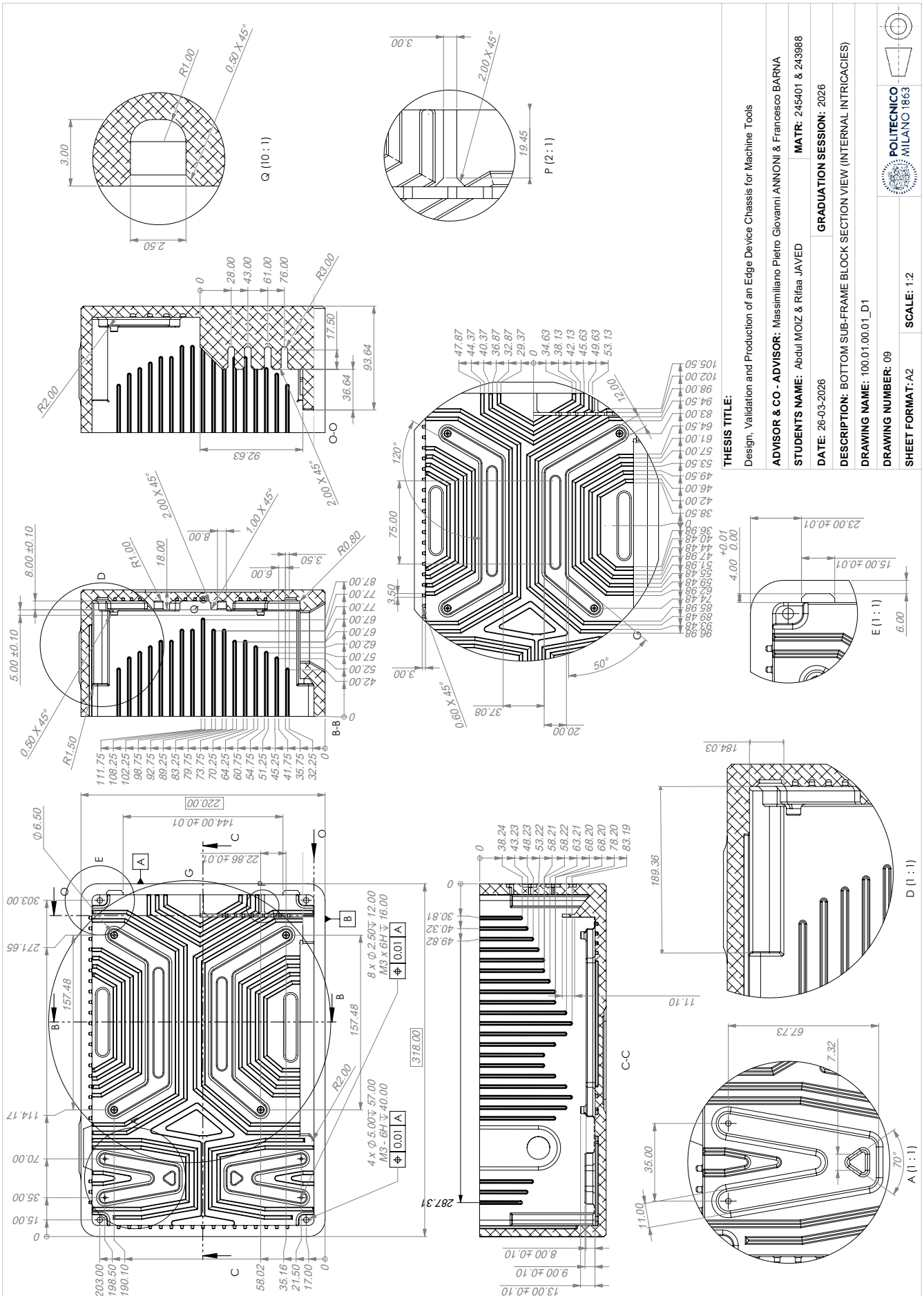
A.7 Teraverse Chassis Top Section View (Top Vent)



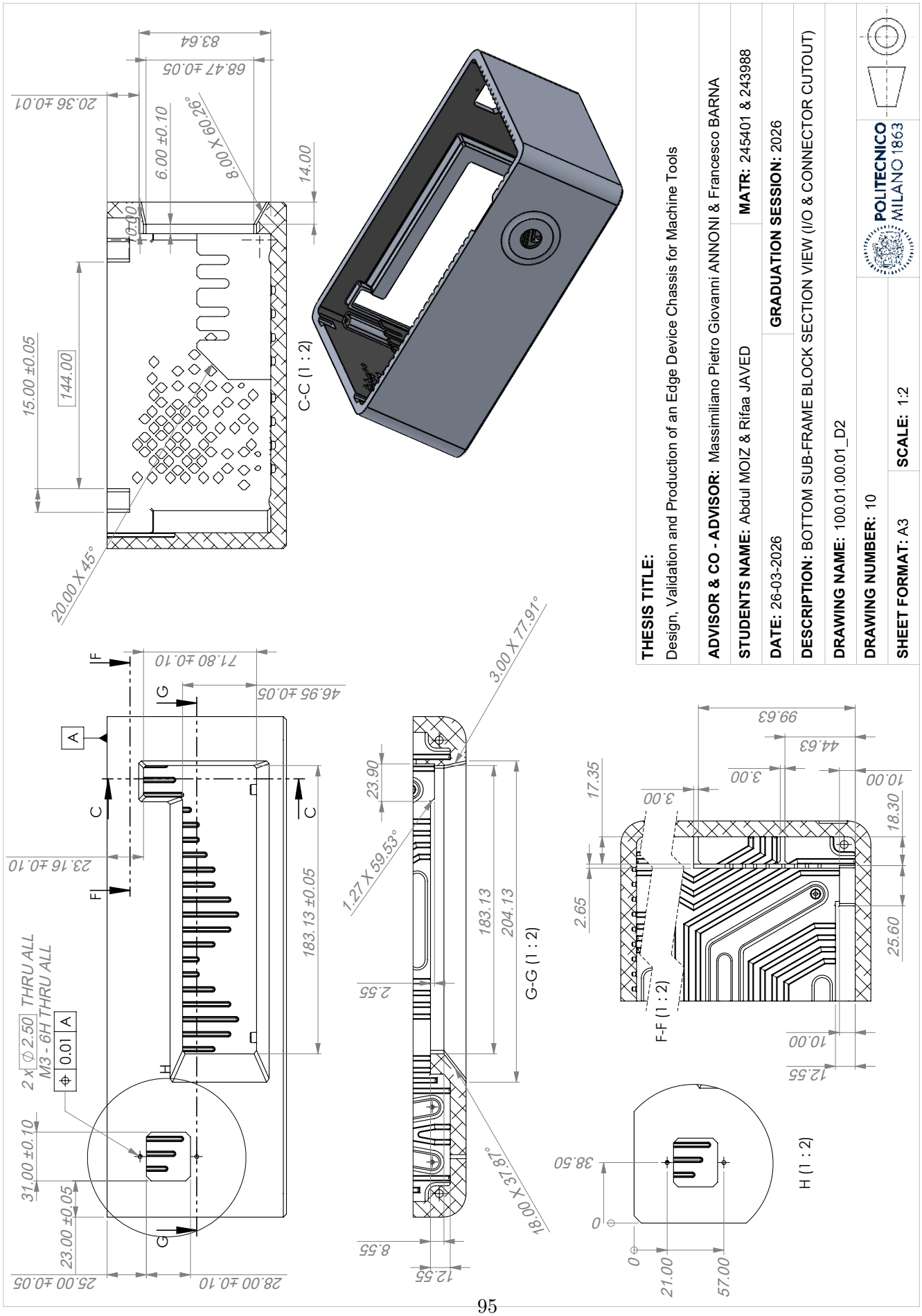
A.8 Bottom Sub-Frame Block (General Views)



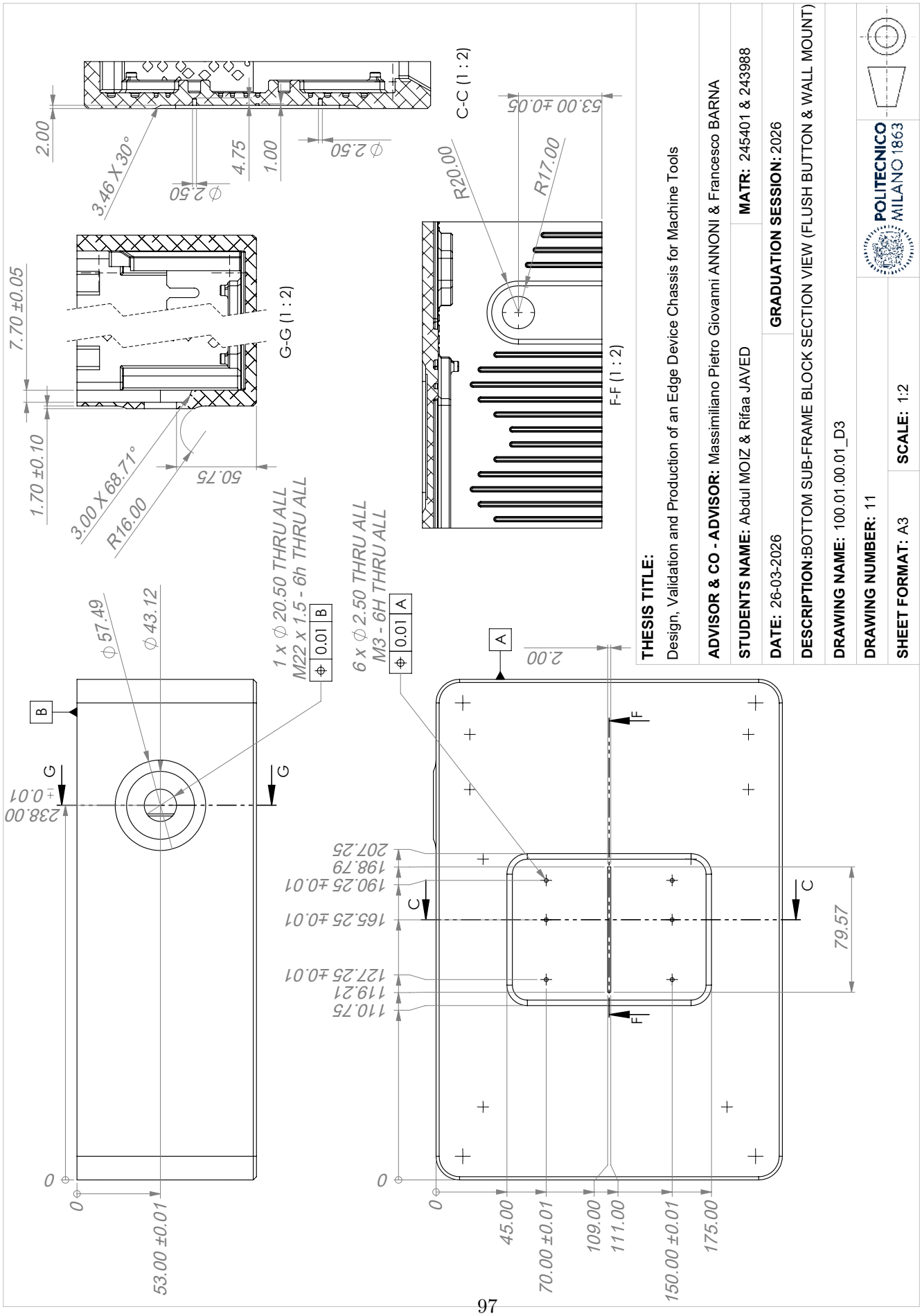
A.9 Bottom Sub-Frame (Internal Intricacies)



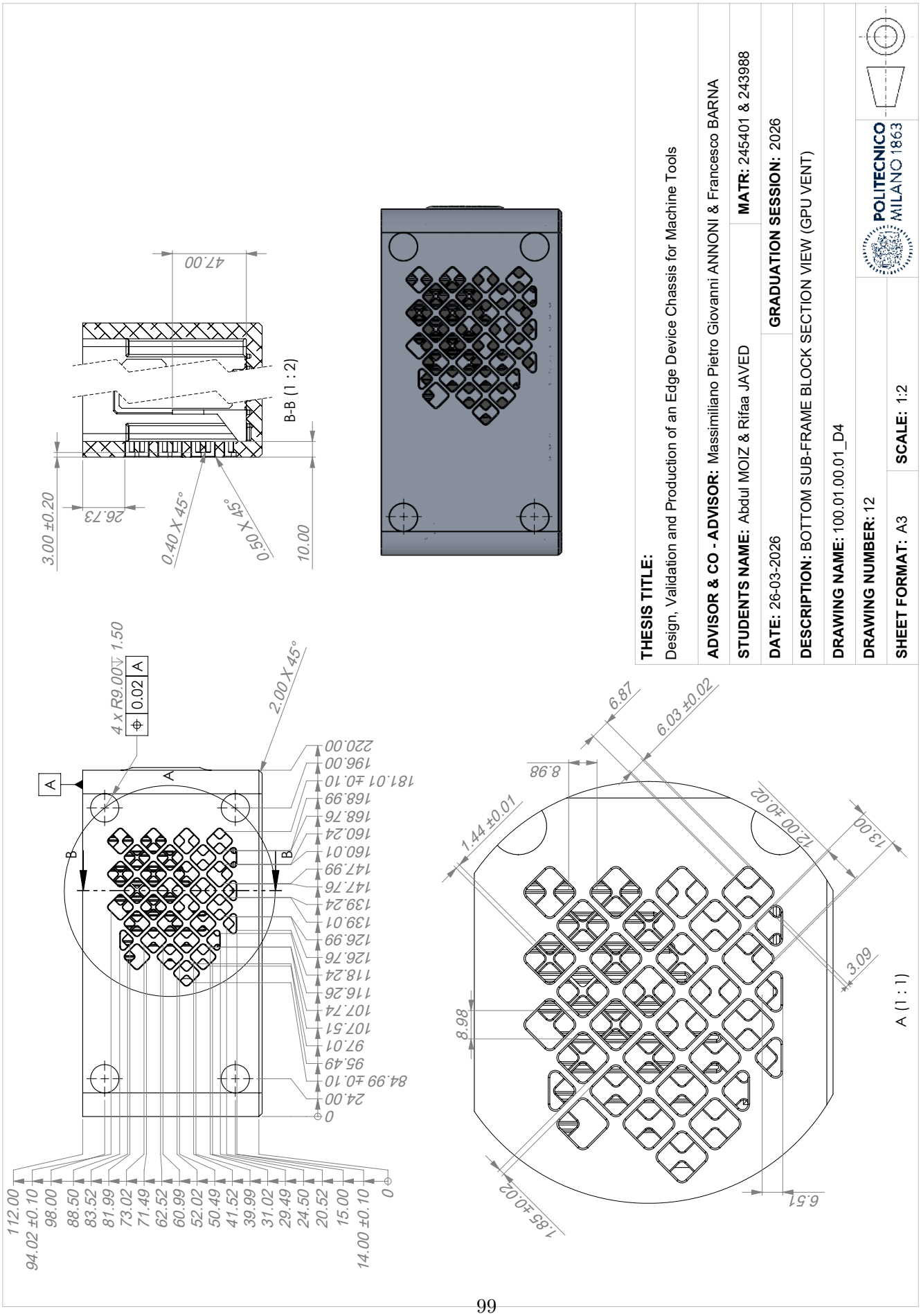
A.10 Bottom Sub-Frame (I/O & Connector Cutout)



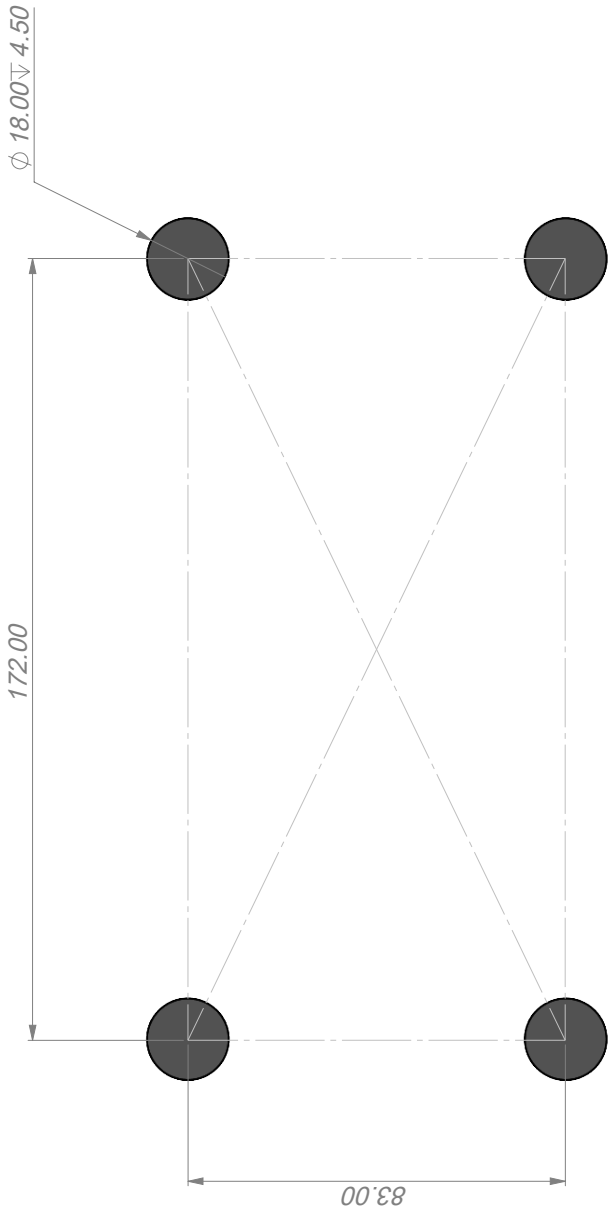
A.11 Bottom Sub-Frame (Flush Button & Wall Mount)



A.12 Bottom Sub-Frame (GPU Vent)



A.13 Silicon Pad Arrangement Footprint



1. ***SILICONE RUBBER, 60 SHORE A ± 5 ARRANGEMENT.***
2. ***FOOTPRINT SKETCH TO BE DETERMINED FOR THE PREDEFINED PLACEMENT SUPPORT.***

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STUDENTS NAME: Abdul MOIZ & Rifaa JAVED **MATR:** 245401 & 243988

DATE: 26-03-2026 **GRADUATION SESSION:** 2026

DESCRIPTION: SILICON PAD ARRANGMENT FOOTPRINT

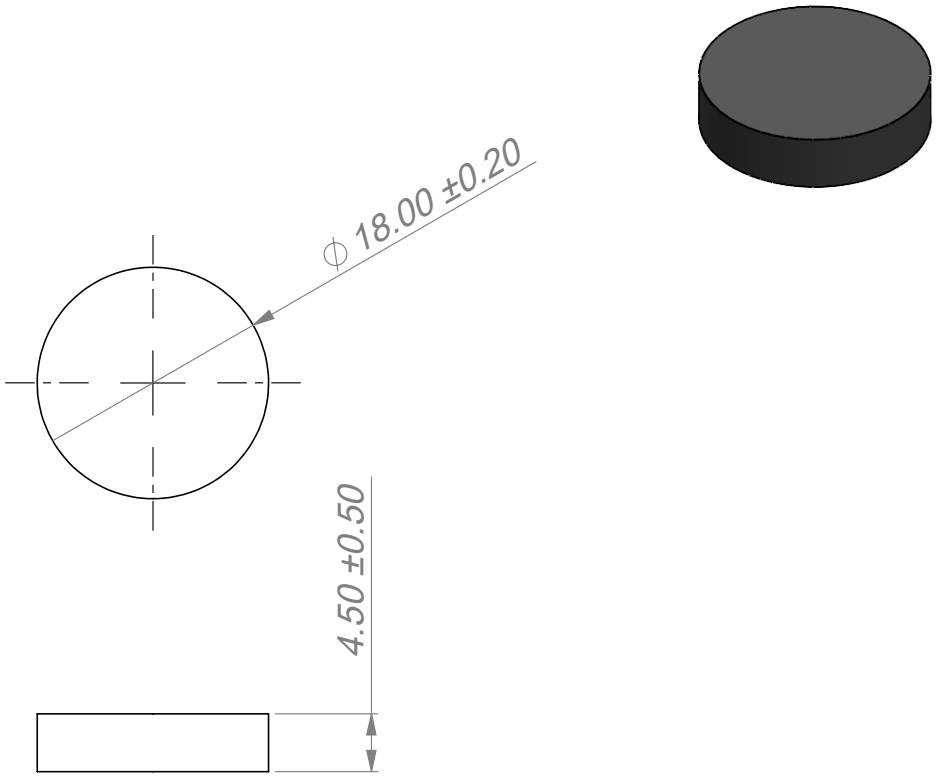
DRAWING NAME: 100.01.01.00

DRAWING NUMBER: 13

SHEET FORMAT: A3 **SCALE:** 1:1

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A.14 Silicon Poly Pad



1. ***SILICONE RUBBER, 60 SHORE A ± 5, COLOR: BLACK***
2. ***ADHESIVE: 3M 9448A DOUBLE-COATED TISSUE TAPE (OR EQUIVALENT).***
3. ***MAX FLASH 0.15MM; TOLERANCES PER ISO 3302-1, CLASS M2.***
4. ***SPI-B2 (MEDIUM POLISH) ON CONTACT FACE.***

THESIS TITLE: Design, Validation and Production of an Edge Device Chassis for Machine Tools		
ADVISOR & CO - ADVISOR: Massimiliano Pietro Giovanni ANNONI & Francesco BARNA		
STUDENTS NAME: Abdul MOIZ & Rifaa JAVED		**MATR:** 245401 & 243988
DATE: 26-03-2026	**GRADUATION SESSION:** 2026	
DESCRIPTION: SILICON POLY PAD		
DRAWING NAME: 100.01.01.01		
DRAWING NUMBER: 14	POLITECNICO MILANO 1863	
SHEET FORMAT: A4	**SCALE:** 2:1	

Appendix B

Bill of Materials

POS.	MAIN ASSEMBLE	ASSEMBLY LEVEL 00	ASSEMBLY LEVEL 01	ASSEMBLY LEVEL 02	DESCRIZIONE	Q.tà	M/B	MATERIAL	MANUFACTURING PROCESS	WEIGHT (KGs)	COD.COMMERCIO
	100.00.00.00				EDGE DEVICE	1	-				
1		100.00.00.01			TERAVERSE CHASSIS TOP	1	M	7075	CNC Milling Operations	1.147	
2		COM-100.00.00.03			DIN RAIL MOUNTING BRACKET	2	B				DINM12CB-RC
3		COM-100.00.00.02			DIN RAIL SAMPLE	1	B				141604
4		MEC040.101021A20306 [M3X6 TCCE 8.8]			Vite Testa Cilindrica Con Esagono ISO4762-M3x10	6	B				
5		CBSTS6-30			M6-30 HEX HEAD SCREW	4	B				
6		SCHNORR-D.3			SCHNORR D.3 INOX	6	B				
7		SCHNORR-D.6			SCHNORR-D.6 INOX	4	B				
		100.01.00.00			BOTTOM SUB-FRAME COMPONENTS ASSEM	1	-				
8			COM-100.01.00.05		Mini ITX MoBo	1	B				ROG STRIX B650E-I
9			COM-100.01.00.02		CONNECTOR PIN HOUSING	1	B				1333N55_IEC
10			MEC040.101031A20316 [M3X16 TSCEI 8.8]		COUNTERSUNK SCREW M3X16	2	B				
11			COM-100.01.00.03		FLUSH MOUNT SWITCH	1	B				6023T17
12			100.01.00.01		BOTTOM SUB-FRAME BLOCK	1	M	7075	CNC Milling Operations	4.745	
13			COM-100.01.00.09		Lexar® NM790 M.2 2280 PCIe GEN 4x4 NVMe SSD	1	B				F5-5200J3636D32GX2-FX5
14			COM-100.01.00.08		Flare X5 RAM DDR5-5200 CL36-36-36-83 1.25V 64GB (2x32GB)	2	B				F5-5200J3636D32GX2-FX5
15			socket button head screw_iso		BUTTON HEAD M3X6 SCREW	8	B				
16			COM-100.01.00.04		CPU COOLING SINK FAN	1	B				NH-L9X65
17			COM-100.01.00.07		NVIDIA RTX™ A1000 8GB GDDR6	1	B				900-5G172-2580-000
18			COM-100.01.00.06		HDPLEX 250W GaN Passive AIO ATX Power Supply	1	B				HDPLEX 250W GaN
			COM-100.01.00.10		AMD Ryzen™ 9 7900 processor 3.7 GHz 64 MB L3	1	B				100-000000590
			100.01.01.00		SILICON POLY PAD STACK ASSEM	1	-				
19				100.01.01.01	SILICON POLY PAD	4	M	Silicon Rubber	Room Temperature Vulcanization (RTV)	0.002	

Appendix C

Configuration-Level DFMEA

DFMEA Table

Item / Function	Failure Mode	Effects	S	Causes	O	Current Controls (Final Configuration)	D	RPN	Mitigation Strategy	Implemented Measure	Target (S/O/D → RPN)
DIN-rail mounting interface	Loss of retention	Detachment, misalignment, downtime	9	Vibration; incomplete engagement	5	Dedicated rear bracket; mounting treated as fixed structural boundary	7	**315**	Constrain rail geometry; secondary retention; engagement verification	-	**9/3/4 → 108**
Mounting / bracket fasteners	Preload loss	Rattle; fatigue initiation	7	Sustained vibration	6	Locally thickened fastening regions; monolithic load path	7	**294**	Controlled torque and defined locking method	Locking washers + torque specification (≥85–90% preload retention)	**7/4/4 → 112**
Threaded bosses (Al 7075)	Thread stripping	Loss of clamping	6	Over-torque; insufficient engagement	5	Integrated boss geometry; local thickening; 7075 stiffness	5	**150**	Minimum engagement rule (≥1–1.5D); torque control	-	**6/3/3 → 54**
Front panel perimeter (micro-milled Al–Al)	Local gap formation	Uncontrolled ingress	7	Tolerance stack; seating irregularity	5	Precision-machined mating surfaces; deterministic seating	7	**245**	Controlled flatness and finish; eliminate gasket dependency	≤0.01 mm flatness; Ra ≤0.4 µm; sharp-edge contact	**7/3/4 → 84**
Vent openings	Blockage by contaminants	Airflow reduction; hotspot risk	8	Chip/oil accumulation	6	Ventilation verified under fixed geometry	9	**432**	Geometry-led ingress control; inspection provision	Stepped internal pathway; no direct line-of-sight ingress	**8/4/6 → 192**
GPU support	Support loosening	PCIe stress; intermittent fault	8	Vibration-induced preload loss	5	Mechanical decoupling of connector loads	7	**280**	Positive-lock geometry; torque verification	Rear machined support wall transferring cantilever loads	**8/3/4 → 96**
Power inlet (IEC C14)	Connector loosening	Power interruption; arcing risk	10	Cable strain; vibration	3	Reinforced panel interface	6	**180**	Strain relief and controlled cut-out fit	Constrained seating via aligned M3 countersunk pockets	**10/2/3 → 60**
Power switch (22 mm)	Rotation / loosening	Control unreliability	6	Repeated interaction; vibration	4	Flush-mount boundary interface	5	**120**	Anti-rotation feature; torque control	Self-locking M22 nut with friction-enhanced interface	**6/3/3 → 54**
Mounting plane geometry	Warpage	Poor DIN engagement	7	Machining distortion	3	Tolerance localisation; functional datum strategy	6	**126**	Defined datum hierarchy; flatness control	≤0.01 mm verified seating deviation	**7/2/4 → 56**
Surface condition (Al 7075)	Corrosion / oxidation	Long-term degradation	5	Humidity; oil mist	6	As-machined baseline	9	**270**	Conditional surface treatment	Type II anodization (10–25 µm)	**5/4/6 → 120**
Handling / installation loads	Local denting	Misfit; airflow restriction	4	Impact during handling	4	Structural stiffness validated under top-load case	6	**96**	Handling notes; packaging constraint	-	**4/3/4 → 48**

Appendix D

Component Datasheets

D.1 Mini-ITX Addendum / Design Guide

Mini-ITX Addendum Version 1.1

To the microATX Motherboard Interface Specification Version 1.2

April 2009

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Revision History

Revision Number	Description	Revision Date
1.1	Minor sentence structure corrections made. Title changed to: 'Mini-ITX Addendum Version 1.1 To the microATX Motherboard Interface Specification Version 1.2' to reflect full name of mATX document name.	Feb, 2009
1.0	Initial release.	Feb, 2009

§

1 Executive Summary

The Mini-ITX addendum to the *microATX Motherboard Interface Specification* details the use of the Mini-ITX form factor standard, developed by Via Technologies Inc, for compatibility with Intel based platforms. This document defines only the specific features in Intel's Mini-ITX based platforms that differ from those of microATX and should be used in conjunction with the governing microATX specification.

A smaller motherboard layout offers system developers the ability to create new and innovative system designs. This smaller version of microATX allows and encourages developers to build within the sub 8 Liter chassis volume for a variety of new applications.

Described within this document are requirements and characteristics of a Mini-ITX motherboard, so that a motherboard may function and fit appropriately when paired with a ***Mini-ITX*** chassis. Beyond this, it does not detail processor, memory, graphics or other system features required to meet the Mini-ITX form factor. These items are left to system designers and integrators within the guidelines of the microATX specification.

Table 1. Mini-ITX Addendum Feature Summary

Feature	**Benefit**
170mm x 170mm motherboard size	Smaller board size enables a smaller system size
Standard microATX 1.2 or later I/O panel	I/O shield does not need to be retooled. Motherboard can be used in a ATX or in a microATX chassis
Same motherboard mounting holes as in microATX	Compatible with microATX chassis. No need to retool current chassis
Current processor and future processor technologies	Chassis will work for multi generation socketed processor technology

This addendum does NOT define:

- Specific power supply form factors
- Thermal design guidance to chassis vendors (covered in TASC guide listed in Reference Documents)

The Mini-ITX addendum to the microATX Specification is a public document intended for widespread application in many types of systems. It is available through a public website located at:

http://www.formfactors.org

1.1 Terminology

Term	Description
SFF (Small form factor)	8-19 liter chassis (IDC* definition)
Ultra SFF (uSFF)	4-8 liter chassis (IDC* definition)
Tiny PC	Less than 4 liter chassis (IDC* definition)

1.2 Reference Documents

The following reference documents are posted on the public web site at http://www.formfactors.org

Document
microATX Motherboard Interface Specification Version 1.2
SFX 12V Power Supply Design Guide
TFX 12V Power Supply Design Guide
Thermally Advantaged Small Chassis OR TASC [pronounced 'task'] (Thermal Design Guide)

1.3 Benefits to Users

Trends in the industry indicate that users require a smaller and lower cost solution for their PC needs. The smaller board size and lower height keep out zones enable a reduced sized chassis as it sits on the user's desk, is mounted on a display, or comes in any other innovative form factor. These changes also enable a PC to be designed into various aesthetic shapes and sizes.

1.4 Benefits to Manufacturers

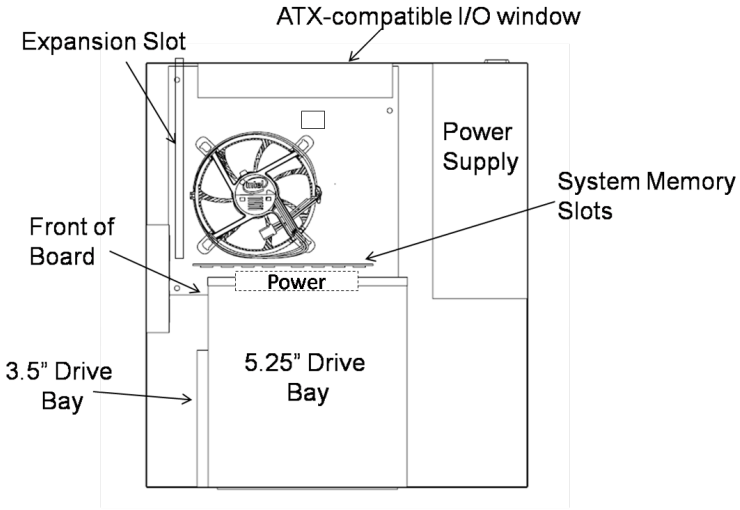
By manufacturing to this Mini-ITX specification, motherboard manufacturers and chassis manufacturers can guarantee a better compatibility between their products. They can also capitalize on the benefits of a reduction in total system costs because of a reduced system size. This specification allows chassis vendors to design their product targeting the soldered down, low power processors all the way up to high performance, multi-core processors. It eliminates the need for them to design targeted chassis for each platform.

§

2 Layout

This section describes the mechanical specification of the Mini-ITX form-factor motherboard. Size, mounting hole placement, connector placement, and component height constraints are specified. System components such as hard drives, disk drives, and power supplies are not specified, however it is generally recommended to consider what would facilitate assembly, as well as not place components such that they block fan inlets. An example layout is depicted in Figure 1.

Figure 1. Example Mini-ITX Layout



Note: Depicted system is approximately 8L with standard desktop components.

2.1 Board dimensions

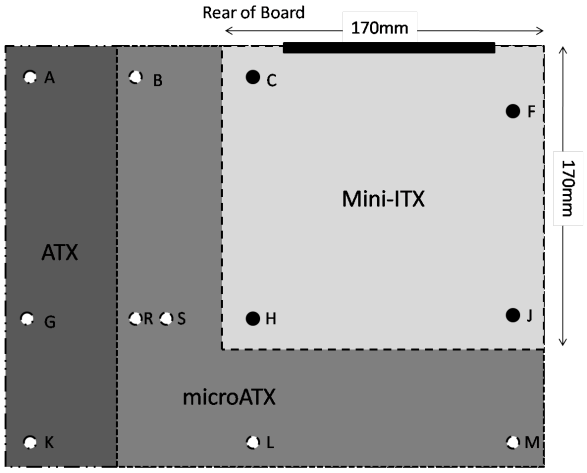
Table 2. Compares ATX, microATX, and Mini-ITX board dimensions

Dimension	ATX	microATX	Mini-ITX
Maximum width Allowable	305mm	244mm	170mm
Maximum depth Allowable	244mm	244mm	170mm

2.2 Mounting Hole Placement

Mini-ITX utilizes a subset of ATX mounting holes. To avoid damage to traces on motherboards, chassis standoffs in any locations not specified should be removable or not implemented at all. See Figure 2 for relative hole location compared to ATX and microATX motherboards.

Figure 2. ATX, microATX, and Mini-ITX Mounting Holes



Not to scale

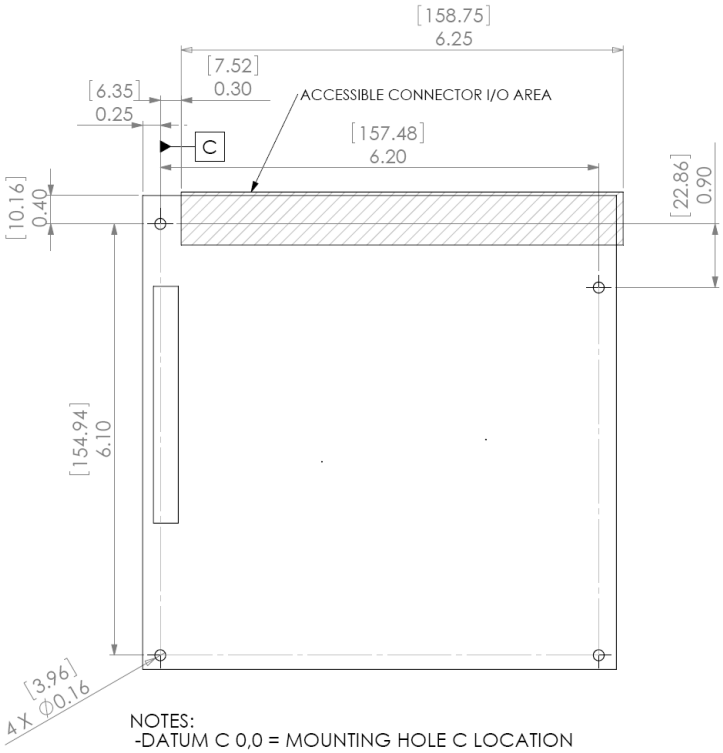
NOTE: Board is shown oriented with the rear of the board towards the top.

NOTE: The lighter portion indicates the approximate region of the Mini-ITX form factor.

Table 3. Motherboard Mounting Hole Locations

Form Factor	Mounting Hole Locations
Mini-ITX	C,F,H,J
microATX	B,C,F,H,J,L,M,R,S
ATX	A,C,F,G,H,J,K,L,M

Figure 3. Mini-ITX Board Diagram



2.3 Connector placement

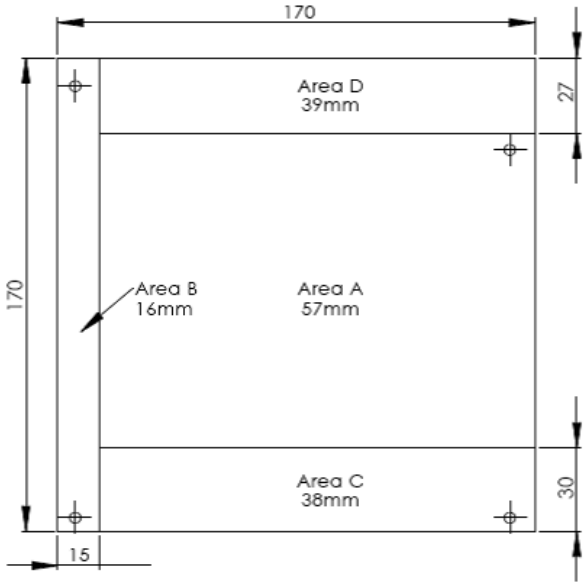
All connector locations as well as allowable placement area for I/O connectors on the back panel are described and can be found in the microATX interface specification.

2.4 Height Constraints

2.4.1 Primary (Component) Side Height Constraints

One major advantages of the Mini-ITX form factor is its backward-compatibility with the ATX specification. The Mini-ITX motherboard can be installed in any ATX chassis. Figure 4 shows the required **maximum component height constraints** for the components on the PC board. For full compliance with Mini-ITX, and to prevent interference with the chassis structure, power supply, or peripherals, the motherboard components should not exceed the height limit in each zone defined. Similarly, compliant power supplies, peripherals, and chassis features should not extend into the motherboard component area.

Figure 4. Mini-ITX Maximum Component Height Restrictions



Notes:

- All dimensions in the above figure are in millimeters (mm).
- The 57mm height restriction in Area A applies to the PC board component height. The actual height of the chassis should include any dynamic excursion considerations for shipping as well as needs to facilitate alternative cooling solutions or airflow considerations.
- For Intel boxed processor fan heat sink, it is strongly recommended not to place components between fan inlet and chassis side vent by leaving space between chassis wall and area A open.
- The component height requirement assumes a motherboard thickness of 1.57 mm (0.062”).

2.4.2 Secondary (Bottom/Solder) Side Height Constraints

No height restraints on secondary side are added or removed from what is specified in the microATX Motherboard Interface Specification.

3 Power Supply Information

Provided the very different needs of the platforms that fit in the small desktop form category, this specification does not attempt to define a standard for the power supply to match with the Mini-ITX motherboard specification. Instead it recommends that manufacturers consider using a:

- SFX, TFX or FlexATX are available power supply form factor for chassis greater than 5 liters
- External power adapter for chassis less than 5 liters

Refer to the microATX Motherboard interface Specification for information on power supply requirements.

D.2 AMD Ryzen 9 7900 Processor Datasheet

L2 Cache	12 MB
L3 Cache	64 MB
Default TDP	65W
Processor Technology for CPU Cores	TSMC 5nm FinFET
Processor Technology for I/O Die	TSMC 6nm FinFET
CPU Compute Die (CCD) Size	71mm²
I/O Die (IOD) Size	122mm²
Package Die Count	3
Unlocked for Overclocking ⓘ	Yes
AMD EXPO™ Memory Overclocking Technology	Yes
Precision Boost Overdrive	Yes
Curve Optimizer Voltage Offsets	Yes
AMD Ryzen™ Master Support	Yes
CPU Socket	AM5
Supporting Chipsets	A620 , X670E , X670 , B650E , B650 , X870E , X870 , B840 , B850
CPU Boost Technology	Precision Boost 2
Instruction Set	x86-64
Supported Extensions	AES , AMD-V , AVX , AVX2 , AVX512 , FMA3 , MMX-plus , SHA , SSE , SSE2 , SSE3 , SSE4.1 , SSE4.2 , SSE4A , SSSE3 , x86-64
Thermal Solution (PIB)	AMD Wraith Prism
Max. Operating Temperature (Tjmax)	95°C
Launch Date	01/14/2023
***OS Support**	Windows 11 - 64-Bit Edition , Windows 10 - 64-Bit Edition , RHEL x86 64-Bit , Ubuntu x86 64-Bit

Connectivity

Native USB 3.2 Gen 2 (10Gbps)	4
Native USB 3.2 Gen 1 (5Gbps)	0
Native USB 2.0 (480Mbps)	1
Native SATA Ports	0
PCI Express® Version	PCIe® 5.0
Native PCIe® Lanes (Total/Usable)	28 , 24
Additional Usable PCIe Lanes from Motherboard	**X670E** 12x Gen4 **X670** 12x Gen4 **B650E** 8x Gen4 **B650** 8x Gen4
NVMe Support	Boot , RAID0 , RAID1 , RAID10
System Memory Type	DDR5
Memory Channels	2
Max. Memory	128 GB
System Memory Subtype	UDIMM
Max Memory Speed	**2x1R** DDR5-5200 **2x2R** DDR5-5200 **4x1R** DDR5-3600 **4x2R** DDR5-3600
ECC Support	Yes (Requires mobo support)

Graphics Capabilities

Graphics Model	AMD Radeon™ Graphics
Graphics Core Count	2
Graphics Frequency	2200 MHz
USB Type-C® DisplayPort™ Alternate Mode	Yes

D.3 Noctua NH-L9x65 chromax.black Datasheet







NOCTUA NH-L9x65 chromax.black

L-Type Premium Cooler

The NH-L9x65 chromax.black is an all-black version of the award-winning NH-L9x65 low-profile cooler, which covers a middle ground between the larger NH-L12 series and the ultra-compact NH-L9i and NH-L9a series. With 65 instead of 37mm height and four instead of two heatpipes, the NH-L9x65 is more powerful than its smaller siblings yet retains the NH-L9i's 95x95mm footprint, which not only guarantees 100% RAM and PCIe compatibility on current motherboards but also makes the cooler more convenient to work with as it doesn't overhang near-socket connectors. Thanks to the highly optimised NF-A9x14 premium fan that supports fully automatic speed control via PWM, the NH-L9x65 runs remarkably quiet. Topped off with the professional SecuFirm2™ multi-socket mounting system for Intel and AMD, Noctua's renowned NT-H1 thermal compound and a 6 year manufacturer's warranty, the NH-L9x65 fuses everything users have come to expect from Noctua's larger coolers into a compact premium package for space restricted systems.

Award-winning NH-L9x65 cooler

Carrying awards and recommendations from more than 100 hardware websites and magazines across the world, the NH-L9x65 has proven its qualities in countless tests. Its winning combination of low height, strong performance and excellent compatibility has made it a default choice for Small Form Factor builds.

100% RAM compatibility

With its compact 95x95mm footprint, the NH-L9x65 does not overhang the RAM slots on Intel LGA1851/LGA1700/LGA1200/LGA115x and AMD AM5/AM4 based motherboards, which ensures easy access to the modules and 100% compatibility with DIMMs that feature tall heat-spreaders or RGB lighting.

chromax.black design

The NH-L9x65 chromax.black is black from head to toe: featuring a black coated heatsink, a black fan with black anti-vibration pads, black fan clips and black mounting parts, it's right at home in all-black builds and easy to integrate with other colour schemes.

6-year manufacturer's warranty

Noctua products are renowned for their impeccable quality and outstanding longevity. Like all Noctua fans, the supplied NF-A9x14 features an MTTF rating of more than 150.000 hours and the entire NH-L9x65 package comes with a full 6-year manufacturer's warranty.

NH-L9x65 HEATSINK SPECIFICATIONS

Socket compatibility	Intel LGA1851, LGA1700, LGA1200, LGA1156, LGA1155, LGA1151, LGA1150 and AMD AM5, AM4
Dimensions	95x95x51 mm
Dimensions with NF-A9x14 HS-PWM	95x95x65 mm
Weight	340 g
Weight with NF-A9x14 HS-PWM	413 g
Material	Copper (base and heat-pipes), aluminium (cooling fins), soldered joints & nickel plating
Fan compatibility	92x92x14 mm, 92x92x25 mm

NF-A9x14 HS-PWM FAN SPECIFICATIONS

Size	92x92x14 mm
Connector	4-pin PWM
Bearing	SSO2
Blade geometry	A-Series with Flow Acceleration Channels
Frame technology	AAO (Advanced Acoustic Optimisation)
Max. input power	2.52 W
Voltage	12 V
MTTF	> 150,000 h

NF-A9x14 HS-PWM	without adaptor	with L.N.A.
Max. rotational speed (+/–10%)	2500 RPM	1800 RPM
Max. airflow	57.5 m³/h	40.8m³/h
Max. acoustical noise	23.6 dB(A)	14.8 dB(A)
Max. static pressure	2.11 mmH_2O	1.06 mmH_2O

CHROMAX by NOCTUA

LOGISTIC DATA

Product name
Noctua NH-L9x65 chromax.black

EAN
9010018000498

UPC
841501100499

Packaging dimensions (HxWxD)
180x134x133 mm

Weight incl. packaging
880 g

Warranty
6 years

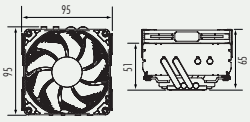
Packaging unit
12 pcs

Packaging dimensions / unit (HxWxD)
438x384x306 mm

Weight incl. packaging / unit
11.60 kg

SCOPE OF DELIVERY

- Black NH-L9x65 heatsink
- NF-A9x14 HS-PWM chromax.black premium fan
- Low-Noise Adaptor (L.N.A)
- NT-H1 thermal compound
- Black SecuFirm2™ mounting-kit
- Noctua metal case-badge

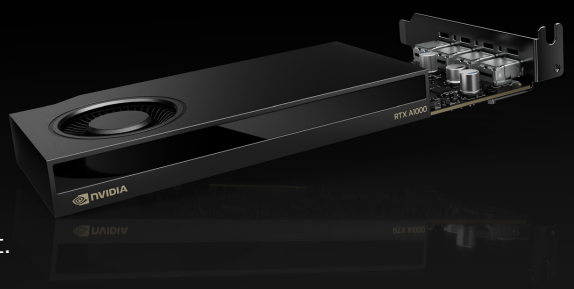


www.noctua.at

D.4 NVIDIA RTX A1000 Datasheet

Datasheet

NVIDIA



NVIDIA RTX A1000

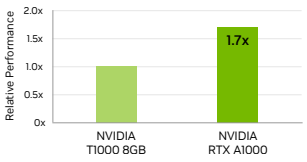
Mighty performance. Minimal footprint.

Small Size, Big Impact—The Ultimate Compact Power

The NVIDIA RTX™ A1000 is a powerful, low-profile GPU that brings RTX-powered real time ray tracing and AI acceleration to a whole new audience. Built on the NVIDIA Ampere GPU architecture, it combines 2,304 CUDA® Cores, 72 third-generation Tensor Cores, and 18 second-generation RT Cores, and 8GB of GDDR6 graphics memory. With the RTX A1000, you can create more compelling visuals, explore new AI-powered workflows, and boost your productivity, all from a small-form-factor solution.

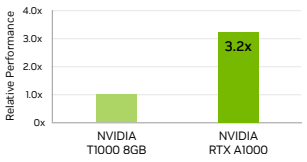
NVIDIA RTX professional graphics cards are certified for a broad range of professional applications, tested by leading independent software vendors (ISVs) and workstation manufacturers, and backed by a global team of support specialists. Get the peace of mind to focus on what matters with the premier visual computing solution for mission-critical business.

Graphics



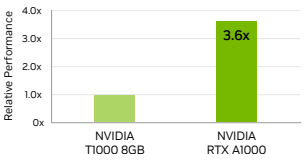
Tests run on an Intel Core i9-12900K Processor @ 3.2GHz (5.2GHz Turbo), 64GB RAM, Windows 11 Enterprise x64, SPECviewperf 2020, NVIDIA Driver 551.57. Relative speedup for 4K Maya score. Performance based on pre-release build, subject to change.

Rendering



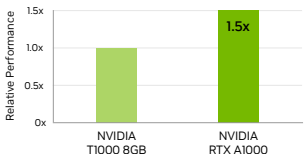
Tests run on an Intel Core i9-12900K Processor @ 3.2GHz (5.2GHz Turbo), 64GB RAM, Windows 11 Enterprise x64, NVIDIA Driver 551.57. Relative speedup for 1080p resolution Arnold render tests. Performance based on pre-release build, subject to change.

Generative AI



Tests run on an Intel Core i9-12900K Processor @ 3.2GHz (5.2GHz Turbo), 64GB RAM, Windows 11 Enterprise x64, Stable Diffusion WebUI v1.7.0 with TensorRT extension, NVIDIA Driver 551.57. Average relative speedup for 512x512 image generation. Performance based on pre-release build, subject to change.

CAD



Tests run on an Intel i9-12900K @ 3.2GHz, 5.20GHz Turbo, 64GB RAM, Windows 11 Enterprise x64, NVIDIA driver 551.57. Results based on SOLIDWORKS 2022 FSAA On, GPU composite scores. Preliminary results on pre-production hardware and software, final performance may vary.

Key Features

- Second-generation RT Cores
- Third-generation Tensor Cores
- PCI Express Gen 4
- Four Mini DisplayPort 1.4a
- AV1 decode support
- DisplayPort with audio
- NVIDIA RTX Experience™
- NVIDIA RTX Desktop Manager software
- NVIDIA RTX IO support
- HDCP 2.2 support
- NVIDIA Mosaic[1] technology

Specifications	
PNY Part Number	VCNRTXA1000-PB
EAN code	3536403399467
GPU memory	8GB GDDR6
Memory interface	128-bit
Memory bandwidth	192GB/s
NVIDIA Ampere-based CUDA® Cores	2304
NVIDIA third-generation Tensor Cores	72
NVIDIA second-generation RT Cores	18
Single-precision performance	6.7 TFLOPS[2]
RT Core performance	13.2 TFLOPS[2]
FP16 Tensor performance	53.8 TFLOPS[3]
Peak INT8 Tensor performance	107.8 TOPS[4]
System interface	PCIe 4.0 x8[5]
Power consumption	Total board power: 50W
Thermal solution	Active
Form factor	6,9 cm H x 16,3 cm L, single slot
Display connectors	4x Mini DisplayPort 1.4a
Max simultaneous displays	4x 4096 x 2160 @ 120Hz 4x 5120 x 2880 @ 60Hz 2x 7680 x 4320 @ 30Hz
Encode/decode engines	1x encode, 2x decode (+AV1 decode)
Graphics APIs	DirectX 12, Shader Model 6.6, OpenGL 4.6[6], Vulkan 1.3[6]

Ready to get started?

To learn more about the NVIDIA RTX A1000, visit:
nvidia.com/rtx-A1000

1 Windows 10 and Linux. | 2 Peak rates based on GPU Boost Clock. | 3 Effective FP16 teraFLOPS (TFLOPS) using the sparsity feature. | 4 Peak INT8 TOPS with sparsity. | 5 RTX A1000 utilizes a full-length PCIe Gen 4 x8 interface. | 6 Product is based on a published Khronos specification and is expected to pass the Khronos conformance testing process when available. Current conformance status can be found at www.khronos.org/conformance

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D.5 HDPLEX 250W GaN AIO ATX PSU Datasheet



Technical Specifications

Wattage: 250W (94% Efficiency).

Input Voltage: 90V-264V 50/60hz

Idle Power: <0.4W/0.1W

Feature

- GaN All-In-One ATX Power Supply
- Smallest ATX PSU in the World!
- Fully Passive and Fanless, Zero db Operation
- PFC+LLC Structure, Level 5 Energy Efficiency
- Two Auto Grade GaN FETs on PFC Stage and Two on LLC Stage
- 1.18W/cm³ Super High Power Density
- Support Sync with a Second Unit
- Aluminum shell casing working with HDPLEX fanless PC chassis to dissipate heat
- Fanless and 100% Silent
- 4 Layer 2oz Copper PCB for high current and fast heat disspation
- Three Stage AC Input Filter Eliminate Grid Noise
- Unibody Flat transformer eliminates noise caused by vibration.
- High Precision 1% Resistor

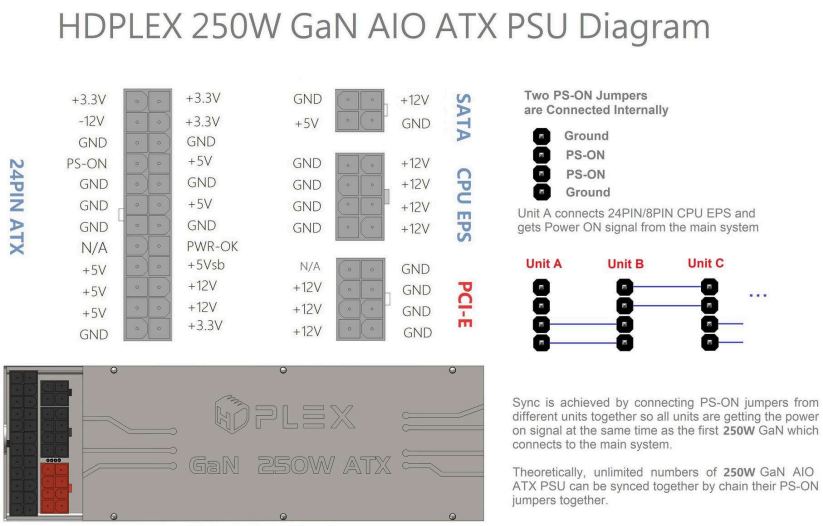
- Four ATX 1KV 8A TTR8MF Full-wave Rectification
- 150μF Rubycon filter CAP and 9000μF Solid Cap
- UVP, OVP, SCP, OPP, OTP
- Fully Modular ATX Output
- Detachable C14 IEC Connector:flexible to support other AC input for custom project

Size: 170(D) x 55 (W) x 25 (H) mm, **Weight:** 360 gram/13 oz,

HDPLEX 250W GaN AIO ATX PSU 3D Engineer Drawing (STP) Download Here

Operating Temperature: -10°C - 75°C

AC Input	100-240VAC 50/60Hz				
DC Output	+3.3V	+5V	+12V	-12V	+5VSb
MAX Output Current	10A	10A	20A	1A	5A
MAX Combined Power	80W				
Total Power	250W				



Molex Part Number for HDPLEX 250W GaN

D.6 G.Skill Flare X5 DDR5 Memory Datasheet

EN

F5-5200J3636D32GX2-FX5

Flare X5
DDR5-5200 CL36-36-36-83 1.25V
64GB (2x32GB)
Intel XMP / AMD EXPO

Designed for DDR5-enabled AMD AM5 platforms, Flare X5 series DDR5 memory is built for high performance in a low-profile design. Featuring AMD EXPO overclocking profiles for easy memory overclocking, users can easily enable overclocked performance by simply enabling EXPO in the BIOS on compatible systems.

Check memory compatibility for your motherboard with the RAM Configurator tool, or check the QVL for a list of compatible motherboards with this memory kit.

Overview

Memory Type	DDR5
Capacity	64GB (32GBx2)
Multi-Channel Kit	Dual Channel Kit
OC Profile Support	Intel XMP 3.0 / AMD EXPO
Tested Speed (Up To) (XMP/EXPO)	5200 MT/s
Tested Latency (XMP/EXPO)	36-36-36-83
Tested Voltage (XMP/EXPO)	1.25V
Registered/Unbuffered	Unbuffered
Error Checking (ECC)	Non-ECC
SPD Speed (Default)	4800 MT/s
SPD Voltage (Default)	1.10V

Back

Warranty	Limited Lifetime
Features	Intel XMP 3.0 & AMD EXPO Profile Ready
Additional Notes	• Do not mix memory kits. Memory kits are sold in matched kits that are designed to run together as a set. Mixing memory kits will result in stability issues or system failure. • Memory kits that are "Intel XMP 3.0 Ready" / "AMD EXPO Profile Ready" includes support for the respective OC profile. • Prior to enabling XMP or EXPO, memory kits will boot at the SPD speed at default BIOS settings with compatible hardware. • For memory kits with XMP or EXPO, enable XMP/EXPO/DOCP/A-XMP profile in BIOS to reach up to the rated potential XMP or EXPO overclock speed of the memory kit, subject to the use of compatible hardware. Enabling XMP or EXPO is an act of overclocking and requires BIOS setting adjustments. Please refer to the "How to Enable XMP/EXPO" guide. • Reaching the rated XMP/EXPO overclock speed and system stability will depend on the compatibility and capability of the motherboard and CPU used. • Usage in any manner inconsistent with manufacturer specifications, warnings, designs, or recommendations will result in lower speeds, system instability, or damage to the system or its components. • Memory module height can be found in the FAQ, under the question "How tall are the memory modules?". • For product support and related questions, please contact the G.SKILL technical support team via email.

1. All images and descriptions are for illustrative purposes only. Please refer to the specifications page for product details.
2. All product specifications and appearances are subject to change without notice. Please check with your retailer or supplier for exact offers. Products may not be available in all markets.
3. Exact specifications and features vary by model. Please refer to the specifications page for product details.
4. PCB color is subject to change without notice.
5. Third-party software support and compatibility depends on software version and operating environment, and are subject to change without notice.
6. Although we strive to present precise and comprehensive information at the time of publication, a small number of items may contain typographic or photographic errors.
7. The product (electrical or electronic equipment) should not be placed in municipal waste. Check local regulations for proper disposal of electronic products.
8. The use of trademark symbols (TM, ®) appearing on this website means that the word text, trademarks, logos, or slogans, is being used as trademark under common laws protection and/or registered as Trademark in U.S. and/or other country/region.
9. Brand names, product names, and trademarks mentioned are properties of their respective companies or owners.
10. Unless otherwise stated, all performance claims are based on theoretical performance. Actual figures may vary in real-world situations.

D.7 Lexar NM790 PCIe Gen4 SSD Datasheet

HOT

Lexar® NM790 M.2 2280 PCIe Gen 4

Sequential read up to 7400MB/s, sequential write up to 6500MB/s

8TB 4TB 2TB 1TB



Compare Compatibility Share

Share



PRODUCTS SUPPORT ABOUT US EXPLORE WHERE TO BUY CHOICE OF CHAMPIONS

Lexar® NM790 M.2 2280 PCIe Gen 4x4 NVMe SSD

Overview Specs Support

High-speed Performance

PCIe Gen4x4 Interface

3D TLC NAND

Specifications

Capacities	512GB/1TB/2TB/4TB/8TB
Form Factor	M.2 2280
Interface	PCIe Gen4x4
Speed	512GB: Read speed up to 7200MB/s[1], write speed up to 4400MB/s[1], random read and write speeds of up to 800,000 IOPs

	1TB: Read speed up to 7400MB/s[1], write speed up to 6500MB/s[1], random read up to 1,000,000 IOPs, random write up to 900,000 IOPs 2TB: Read speed up to 7400MB/s[1], write speed up to 6500MB/s[1], random read up to 1,000,000 IOPs, random write up to 900,000 IOPs 4TB: Read speed up to 7400MB/s[1], write speed up to 6500MB/s[1], random read and write speeds of up to 900,000 IOPs 8TB: Read speed up to 7000MB/s[1], write speed up to 6200MB/s[1], random read up to 850,000 IOPs, random write up to 900,000 IOPs
Operating Temperature	0°C to 70°C (32°F to 158°F)
Storage Temperature	-40°C to 85°C (-40°F to 185°F)
Dimensions (L x W x H)	512GB-4TB：80 x 22 x 2.45 mm (3.15" x 0.87" x 0.10") 8TB: 80 x 22 x 3.75 mm (3.15" x 0.87" x 0.148")
Weight	512GB-4TB：6g / 0.013 lbs 8TB: 7.6g / 0.017 lbs
Warranty	Five-year limited warranty
Shock-resistant	1500G, duration 0.5ms, Half Sine Wave
Vibration-resistant	10~2000Hz, 1.5mm, 20G, 1 Oct/min, 30min/axis (X,Y,Z)
TBW	512GB: 500TBW, 1TB: 1000TBW, 2TB: 1500TBW,4TB: 3000TBW, 8TB: 60 TBW
MTBF	1,500,000 Hours

[1] Up to 7400MB/s read transfer, up to 6500MB/s write. Speeds based on internal testing. Actual performance may vary.
[2] Comparison based on internal testing. Actual performance may vary.

Product Numbers

D.8 IEC C14 Panel Mount Connector Datasheet

McMASTER-CARR®

IEC Connector

Screw-on Male, Quick-Disconnect Terminal, C14, 10A UL



1-49 Each $5.05
50-249 $4.29
250 or more $3.53

1333N55

Connection Type	Straight Blade
Electrical Connector Component	Receptacle
Receptacle Type	Single
Gender	Male
Shape	Straight
IEC Style	C14
Grounding	Grounded
Number of Blades	3
Voltage	250V AC
Current (Rating)	10A (UL), 10A (IEC)
Frequency	50 Hz, 60 Hz
Wire Connection Type	Quick-Disconnect Terminals
Terminal	
Length	0.93"
Width	1/4"
Thickness	0.032"
For Fuse	
Overall Length	20 mm
Overall Diameter	5 mm
Housing Material	Plastic
Mount Type	Screw On
Mounting Location	Panel
For Panel Cutout	
Height	1.24"
Width	1.08"
For Panel Thickness	0.24"
Mounting Hole Diameter	0.14"
Number of Mounting Holes	2
Temperature Range	-10° to 155° F
Environmental Rating	IP40
Shock Protection Class	I
Specifications Met	UL Recognized Component, C-UL Recognized Component, UL 94 V-0, CSA Certified, CE Marked, IEC 60320, ENEC Marked
Color	Black
RoHS	RoHS 3 (2015/863/EU) compliant with exemption 6(c) - Lead in copper alloy
REACH	REACH (EC 1907/2006) (06/25/2025, 250 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Czech Republic
Schedule B	853669.5050
ECCN	EAR99

Pair these connectors with standard IEC power cords to bring power into or out of your electronic devices. Often used to convey power from wall outlets, there’s no need to wire your devices to an external power source. Instead, wire these connectors into your device with the terminals on the back of each connector. Most meet U.S. or international standards for safety.

Receptacles are often installed in electrical devices.

Most also include shock protection.

Class I shock protection means they're insulated and have a protective ground to prevent electrical shocks.

Male receptacles are commonly used to bring power into an electronic device. Some accept a fuse to prevent short circuits and circuit overloads from damaging your devices. The fuses are sold separately.

Screw-on connectors mount to devices with any panel thickness, as long as you can drill mounting holes into the device.

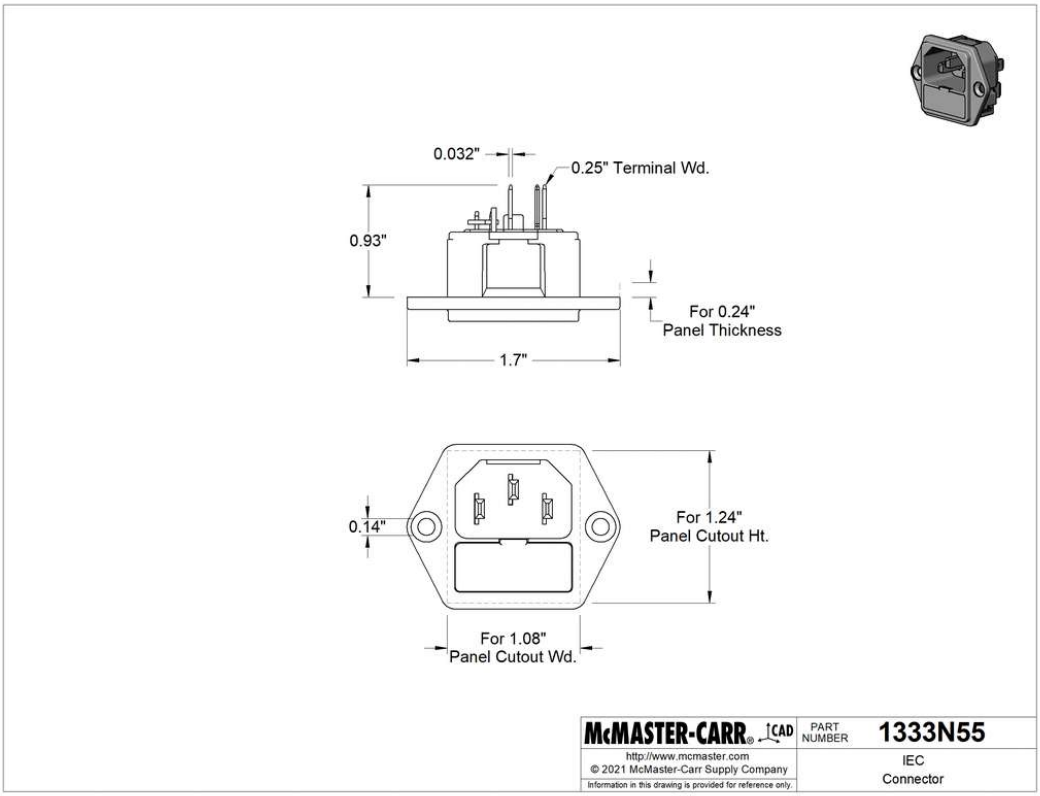
Quick-disconnect terminal wire connections are faster to wire than screw and tab terminal connections. The terminals slide together with the quick-disconnect terminals on your wiring and are easily disconnected by hand, but still provide a strong hold.

IP-rated connectors meet standards for protecting you from making contact with a live circuit. The larger the first digit, the smaller the object it protects against.

And an IP40 rating means wire and other objects larger than 1 mm won't get in.

Connectors with a UL 94 rating have passed one of UL's flame tests.

UL 94 V-0 means they self-extinguish within 10 seconds if they catch fire and won’t spread flames from dripping.



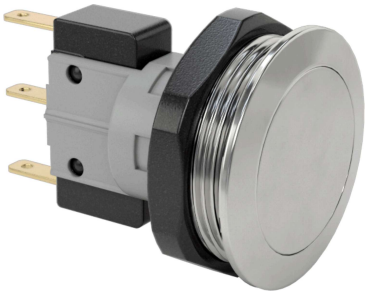
The information in this 3-D model is provided for reference only.

D.9 22mm Flush Push Button Switch Datasheet

McMASTER-CARR®

Flush-Mount Panel-Mount Push-Button Switch

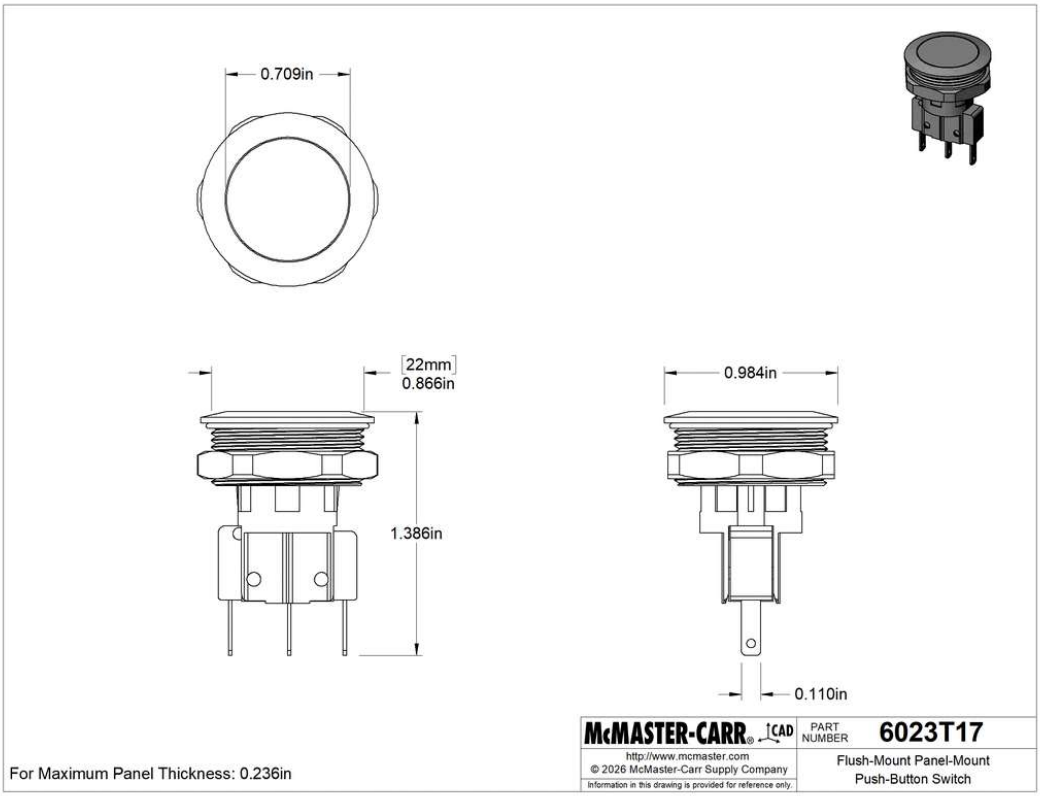
for 22 mm Panel Diameter



$21.29 Each
6023T17

Switch Type	Manual
Mounting Location	Panel
For Panel Cutout Diameter	22 mm
For Panel Cutout Diameter	7/8"
Actuator Style	Push Button
Push-Button Style	Flush
Push-Button Shape	Round
Actuator Material	Stainless Steel
Actuator Base Material	Stainless Steel
Illumination	Not Illuminated
Number of Circuits Controlled	1
Switch Starting Position	1 Off (Normally Open) or 1 On (Normally Closed)
Switch Action	Springs Back (Momentary)
Number of Terminals	3
Industry Designation	SPDT
Switching Current @ Voltage	5 A @ 250 V AC/30 V DC
Maximum Voltage	30V DC 250V AC
Diameter	1"
For Maximum Panel Thickness	3/8"
Depth Behind Panel	1 5/16"
Wire Connection Type	Quick-Disconnect Terminals
Quick-Disconnect Tab Width	0.11"
Environment	Submersible
Environmental Rating	IP40, IP67, IK08
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/25/2025, 250 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Switzerland
Schedule B	853650.9035
ECCN	EAR99

Because these switches mount flush against a panel, they're easy to clean and hard to damage. They're rated IP67 for protection from temporary submersion.



The information in this 3-D model is provided for reference only.