Jewellery Box Interactive Installation - Technical Recommendations

Project: ENBD Pearl Museum - Jewellery Box Interactive
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Executive Summary

This document provides comprehensive technical recommendations for implementing the jewellery box interactive installation at the ENBD Pearl Museum. The system comprises 3 interactive plinths connected to a management node, which interfaces with the Q-SYS show control system in the server room. Based on analysis of the project requirements and the existing design documentation, **I recommend an Ethernet-based architecture** for maximum reliability, bidirectional communication capability, and seamless Q-SYS integration.

⚠️ IMPORTANT CORRECTION NOTICE - NOVEMBER 3, 2025

ISSUE IDENTIFIED: The original management node hardware recommendations (ASUS PN51, Intel NUC, Helix) were **INCORRECT** as they only provide 2 native Ethernet ports. This system requires **4 Ethernet ports**:
- 3x connections to plinths (SH3-C5, SH3-C6, SH3-C7) via 5m Cat6 cables
- 1x connection to Q-SYS server room via 40m Cat6a cable

CORRECTED RECOMMENDATIONS: This document now provides TWO viable hardware solutions:

OPTION 1: Industrial Mini PC with 4 Native Ethernet Ports (RECOMMENDED) ⭐

- **Model:** Qotom Q355G4-S02 (Intel i5-5200U, 4x Gigabit LAN)
- **Cost:** ~$470 (with rack shelf)
- **Key Benefits:** Fanless (silent), industrial-grade, single device, 36W power
- **Dimensions:** 187mm x 140mm x 42mm (fits in 1U rack)

OPTION 2: Mini PC + Managed Ethernet Switch

- **Configuration:** Intel NUC 11 Pro + TRENDnet 5-port switch (or Netgear GS305E budget)
- **Cost:** ~$725 (industrial) or ~$585 (budget)
- **Key Benefits:** Modern processor, expandability, modular architecture

PRIMARY RECOMMENDATION: Qotom Q355G4 for best reliability, cost-effectiveness, and silent operation in a museum environment.

See Section 3 (pages 8-20) for complete corrected specifications with exact dimensions, detailed comparisons, and procurement guidance.

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1. Communication Protocol Decision

1.1 Plinth to Management Node Communication (5m runs)

RECOMMENDATION: Cat6 Ethernet with OSC over UDP

Rationale:

Why NOT DMX:
- **Unidirectional Limitation:** Standard DMX512 is unidirectional (controller → devices). While RDM (Remote Device Management) adds bidirectional capability, it's primarily designed for lighting fixtures and not well-suited for custom control applications
- **Limited Data Rate:** DMX512 runs at 250 kbit/s with 512 channels per universe - adequate but inflexible for future expansion
- **Protocol Complexity:** Would require DMX encoding/decoding at each plinth and custom protocol mapping
- **Q-SYS Integration:** Q-SYS doesn't natively handle DMX as a control protocol (it's primarily for audio/video/control systems)
- **Bidirectional Requirement:** Your system needs SEND (button events, switch status) and RECEIVE (motor control, LED commands) - this is cumbersome with DMX/RDM

Why Ethernet (Cat6):
- **Native Bidirectional:** Full-duplex communication allows simultaneous send/receive
- **OSC Compatibility:** Open Sound Control (OSC) over UDP is explicitly mentioned in your design document and is natively supported by Q-SYS
- **Future-Proof:** Sufficient bandwidth (1 Gbps) for any future enhancements
- **Q-SYS Native:** Q-SYS Core has built-in Ethernet networking and excellent OSC support
- **Reliability:** At 5m, Cat6 is extremely reliable with minimal EMI concerns
- **Standardization:** Uses standard IT networking protocols, easier to troubleshoot and maintain
- **Cost-Effective:** Cat6 cable and RJ45 connectors are readily available and inexpensive

1.2 Management Node to Q-SYS Server Room (40m run)

RECOMMENDATION: Cat6a Shielded (STP) Ethernet

Rationale:

- **Q-SYS Native Protocol:** Q-SYS Core is network-based and designed for Ethernet connectivity
- **Distance:** 40m is well within the 100m Cat6a specification
- **Shielding:** S/FTP (shielded/foiled twisted pair) provides protection against EMI in commercial environments where lighting, motors, and AV equipment create electrical noise
- **10 Gigabit Capable:** Cat6a supports 10GBASE-T up to 100m, providing future-proofing
- **OSC/TCP/UDP:** Q-SYS supports OSC, TCP, and UDP protocols natively - no protocol conversion needed
- **Reliability:** Proven technology for mission-critical AV installations

1.3 Protocol Architecture

```
Plinth ←→ Management Node: OSC over UDP (Port 5000-5005)
Management Node ←→ Q-SYS Core: OSC over UDP (Port 5010)
                                or TCP/IP (Port 1700-1710)
```

Message Structure:
- Button Press: `/plinth/[1-3]/button/press`
- Button Release: `/plinth/[1-3]/button/release`
- Maintenance Switch: `/plinth/[1-3]/maintenance [0|1]`
- Motor Control: `/plinth/[1-3]/motor/open` or `/plinth/[1-3]/motor/close`
- LED Control: `/plinth/[1-3]/led [0-255]` (brightness) or `/plinth/[1-3]/led/pulse`

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2. Plinth Hardware Recommendations

2.1 Recommended Solution: Raspberry Pi 4 Model B (4GB) with Industrial Accessories

Model: Raspberry Pi 4 Model B, 4GB RAM
Part Number: RPI4-MODBP-4GB

Why Raspberry Pi 4:

PROS:
- **Native Ethernet:** Built-in Gigabit Ethernet (no shields or adapters needed)
- **Sufficient I/O:** 40-pin GPIO header provides ample digital I/O for button, switch, LED, and motor control
- **Processing Power:** Quad-core ARM processor can handle network protocols, motor control, and logic
- **Operating System:** Linux-based (Raspberry Pi OS) allows use of proven libraries (Python OSC, pigpio for motor control)
- **Development:** Easy to program and test; large community support
- **Reliability:** Proven in many installation projects worldwide
- **Cost-Effective:** ~$55 USD per unit
- **Remote Access:** Can be remotely accessed via SSH for diagnostics and updates

CONS & MITIGATIONS:
- **SD Card Failure Risk:** Standard SD cards can fail in 24/7 installations
- MITIGATION: Use industrial-grade SD cards (SanDisk High Endurance, Samsung PRO Endurance) rated for continuous operation
- ALTERNATIVE: Use USB boot with industrial USB drive, disabling SD entirely
- **No Real-Time OS:** Linux is not real-time, but for this application (motor control with stepper driver doing the timing), it’s adequate
- **Power Supply:** Requires stable 5V power
- MITIGATION: Use official Raspberry Pi power supply (5V/3A) or industrial DIN-rail power supply

Alternative Considered: Arduino (Not Recommended)

Why Arduino is Less Suitable:
- **Ethernet Not Native:** Requires Ethernet shield (Arduino Uno R4 WiFi has networking, but limited)
- **Limited Processing:** Harder to implement robust OSC protocol handling

- **Programming Complexity:** Implementing network protocols and multi-tasking is more difficult
- **No Operating System:** Bare-metal programming increases development time and reduces flexibility
- **Maintenance:** Harder to remotely diagnose and update

2.2 Complete Plinth Hardware Specification

Each plinth requires:

Component	Specification	Part Number / Model	Purpose
Controller	Raspberry Pi 4 Model B, 4GB RAM	RPI4-MODBP-4GB	Main controller
Storage	Industrial microSD Card, 32GB	SanDisk High Endurance SDSQQNR-032G	Operating system & software
Power Supply	5V/3A USB-C Power Supply	Official RPi PSU (SC0218)	Power for Raspberry Pi
Stepper Driver	Stepper Motor Driver Board	TB6600 or TMC2209 (quiet)	Drive stepper motor with JST connector
Case/Enclosure	DIN-rail mountable enclosure	Phoenix Contact EMG 22-B or similar	Protection and mounting inside plinth
LED Driver (if needed)	MOSFET or transistor for LED control	IRLZ44N MOSFET	PWM control for button LED
Connectors	JST connector (3-pin) for motor	Pre-wired cable to TB6600	Connect to stepper motor
Connectors	Screw terminals or connector block	Phoenix Contact or Wago	Button and maintenance switch wiring

2.3 Raspberry Pi I/O Allocation

GPIO Pin	Function	Connection
GPIO 17	Digital Input (Pull-up)	Button Press Detection
GPIO 27	Digital Input (Pull-up)	Maintenance Switch
GPIO 22	PWM Output	Button LED Control
GPIO 23	Digital Output	Stepper STEP signal
GPIO 24	Digital Output	Stepper DIRECTION signal
GPIO 25	Digital Output	Stepper ENABLE signal
GND	Ground	Common ground for all devices
5V	Power Output	Power LED if needed (through resistor)

2.4 Stepper Motor Driver Selection

Recommended: TMC2209 Driver Module

- **Silent Operation:** Important for museum environment (nearly silent operation)
- **Current Control:** 2.8A peak current, adjustable via potentiometer
- **Voltage:** Operates on 12-24V (supplied separately to driver, not from Pi)
- **Interface:** STEP/DIR interface compatible with GPIO
- **Protection:** Over-temperature, short-circuit protection
- **Cost:** ~$15 USD per unit

Alternative: TB6600 Driver

- **Higher Current:** 4A peak, suitable for larger steppers
- **More Affordable:** ~$8 USD
- **Noisier:** Audible motor noise (may be acceptable)

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3. Management Node Specifications

⚠️ CORRECTION - ETHERNET PORT REQUIREMENT

CRITICAL ISSUE IDENTIFIED: The previously recommended hardware (ASUS PN51, Intel NUC, Helix) typically only provides 2 native Ethernet ports, but this system requires **4 Ethernet ports**:
- 3x Ethernet connections to plinths (5m each)
- 1x Ethernet connection to Q-SYS server room (40m)

The following corrected recommendations provide **TWO viable hardware solutions** that accurately meet the 4-port requirement for a robust, industrial-grade 2+ year museum installation.

3.1 CORRECTED RECOMMENDATIONS - TWO OPTIONS

OPTION 1: Industrial Mini PC with 4+ Native Ethernet Ports ⭐ RECOMMENDED

This option uses a purpose-built networking appliance with 4 or more native Gigabit Ethernet ports, eliminating the need for USB adapters or separate switches.

Recommended Models:

Primary Recommendation: Qotom Q355G4

Manufacturer: Qotom
Model: Q355G4
Processor: Intel Core i5-5200U (Broadwell-U, 2.2GHz base, up to 2.7GHz turbo, 15W TDP)
Part Number: Q355G4-S02

Key Specifications:

Parameter	Specification
Processor	Intel Core i5-5200U (dual-core, 2.2-2.7GHz, AES-NI support)
RAM	8GB DDR3L SO-DIMM (expandable, 1600MHz)
Storage	128GB mSATA SSD + 2.5” SATA bay for expansion
Ethernet Ports	**4x Intel Gigabit LAN (Intel i210-AT chipset)**
Additional I/O	4x USB 3.0, 2x USB 2.0, 1x HDMI, 1x VGA, 1x RS232 COM
Expansion	1x Mini PCIe slot (for WiFi/4G if needed)
Power Supply	12V DC, 3A (36W) - external adapter included
Cooling	**Fanless** - aluminum chassis with passive cooling
Operating System	Windows 10/11, Ubuntu 22.04 LTS, or other Linux distributions
Operating Temp	0°C to 50°C (commercial); can operate to 60°C
Certifications	CE, FCC, RoHS
MTBF	>50,000 hours (5.7 years continuous operation)

Physical Dimensions:

Dimension	Measurement (mm)	Measurement (inches)
Width	187 mm	7.36”
Depth	140 mm	5.51”
Height	42 mm	1.65”
Weight	1.0 kg	2.2 lbs

Rack Mounting:
- **Rack Space Required:** 1U (with custom shelf or bracket)
- **Mounting Method:** Place on vented 1U rack shelf (Middle Atlantic U1 or similar)
- **Rack Depth:** Fits in shallow racks (140mm/5.5” depth + 50mm clearance for cables = 200mm total)
- **Recommended Shelf:** Middle Atlantic U1 vented shelf (19” x 9.5” deep)

Estimated Cost:
- **Mini PC (8GB RAM, 128GB SSD):** $380-$450 USD
- **1U Rack Shelf:** $40-$60 USD
- **Total:** ~$450-$510 USD

Network Port Allocation:

Port	Connection	Purpose
LAN1	Plinth 1 (SH3-C5) - 5m Cat6	OSC communication with Plinth 1
LAN2	Plinth 2 (SH3-C6) - 5m Cat6	OSC communication with Plinth 2
LAN3	Plinth 3 (SH3-C7) - 5m Cat6	OSC communication with Plinth 3
LAN4	Q-SYS Core - 40m Cat6a STP	OSC/TCP to show control system

PROS:
- ✅ **4 native Gigabit Ethernet ports** - no adapters or hubs needed
- ✅ **Fanless operation** - silent, no moving parts to fail, ideal for museum environment
- ✅ **Industrial-grade reliability** - designed for 24/7 networking applications (firewalls, routers)
- ✅ **Low power consumption** - 36W maximum, energy efficient
- ✅ **Compact size** - fits easily in 1U rack space with room to spare
- ✅ **AES-NI hardware acceleration** - enhances security and encryption performance
- ✅ **Proven platform** - widely used in firewall/routing applications (pfSense, OPNsense)
- ✅ **Metal chassis** - robust construction for long-term reliability
- ✅ **Remote management** - full SSH access for diagnostics and updates
- ✅ **No USB adapters** - eliminates potential points of failure

CONS:
- ⚠️ Older generation processor (5th gen Intel) - still adequate for networking tasks but not latest technology
- ⚠️ Limited availability - may require ordering from specialized vendors or international suppliers
- ⚠️ Higher initial cost compared to Option 2

Alternative Model: Protectli Vault VP4650

Manufacturer: Protectli
Model: Vault VP4650 (FW4C series)

Key Specifications:
- **Processor:** Intel Core i5-8250U (quad-core, 1.6-3.4GHz, 15W TDP)
- **RAM:** 8GB DDR4-2400 SO-DIMM
- **Storage:** 120GB M.2 NVMe SSD
- **Ethernet: 4x Intel Gigabit LAN (Intel i211-AT)**
- **Cooling:** Fanless, aluminum chassis
- **Dimensions:** 146mm (W) x 145mm (D) x 54mm (H) / 5.75” x 5.7” x 2.1”
- **Weight:** 1.3 kg / 2.86 lbs

Estimated Cost: $550-$650 USD (+ rack shelf)

PROS:
- ✅ Newer 8th gen processor (better performance)
- ✅ DDR4 memory (faster than DDR3L)
- ✅ NVMe storage (faster boot and operation)
- ✅ US-based manufacturer with excellent support
- ✅ 4 native Gigabit Ethernet ports

CONS:
- ⚠️ Higher cost (~$200 more than Qotom)
- ⚠️ Larger footprint (5.75” x 5.7” vs Qotom’s slimmer profile)

OPTION 2: Mini PC (2 ports) + Managed Ethernet Switch

This option combines a standard dual-port mini PC with a small industrial managed Ethernet switch, providing 4+ total Ethernet ports through a switch-based architecture.

Hardware Configuration:

Component A: Mini PC (2 Native Ethernet Ports)

Recommended Model: Intel NUC 11 Pro (NUC11TNHi5)

Manufacturer: Intel
Model: NUC11TNHi5

Key Specifications:

Parameter	Specification
Processor	Intel Core i5-1135G7 (quad-core, 2.4GHz base, up to 4.2GHz turbo, 28W TDP)
RAM	8GB DDR4-3200 SO-DIMM
Storage	256GB M.2 NVMe SSD (PCIe 4.0)
Ethernet Ports	**2x Intel Gigabit LAN (Intel i219-V + i225-LM 2.5GbE)**
Additional I/O	4x USB 3.1, 2x USB-C (Thunderbolt 4), HDMI, DisplayPort
Power Supply	19V DC, 90W external adapter
Cooling	Low-noise fan (can be configured for quiet operation)
Operating System	Windows 11 Pro or Ubuntu 22.04 LTS
Dimensions	117mm (W) x 112mm (D) x 42mm (H) / 4.6” x 4.4” x 1.65”
Weight	0.7 kg / 1.5 lbs

Estimated Cost: $450-$550 USD (barebone + RAM + SSD)

Component B: Industrial Managed Ethernet Switch (5-8 ports)

Recommended Model: TRENDnet TI-PG541i (Industrial 5-Port Gigabit PoE+ Managed Switch)

Manufacturer: TRENDnet
Model: TI-PG541i

Key Specifications:

Parameter	Specification
Total Ports	**5x Gigabit Ethernet (10/100/1000 Mbps)**
PoE Capability	4x PoE+ ports (up to 30W per port, 120W total budget) - not required but available
Management	Web-based GUI, CLI, SNMP v1/v2c/v3
Switching Capacity	10 Gbps
Features	VLAN support (up to 256), QoS, IGMP snooping, port mirroring, loop detection
Mounting	**DIN-rail mountable** or wall-mount (included brackets)
Power Supply	Redundant dual DC inputs (12-52V, 2A) or single AC input (100-240V)
Operating Temp	-40°C to 75°C (-40°F to 167°F)
Housing	IP30-rated metal enclosure
Dimensions	144mm (W) x 110mm (D) x 32mm (H) / 5.67” x 4.33” x 1.26”
Weight	0.6 kg / 1.32 lbs
Certifications	CE, FCC, RoHS

Estimated Cost: $150-$200 USD

Alternative Switch Option: Netgear GS305E (Budget Option)

Manufacturer: Netgear
Model: GS305E (5-Port Gigabit Managed Switch)

Key Specifications:
- **Ports:** 5x Gigabit Ethernet
- **Management:** Web-based GUI, basic VLAN and QoS
- **Dimensions:** 94mm x 100mm x 27mm / 3.7” x 3.9” x 1.1”
- **Weight:** 0.25 kg / 0.55 lbs
- **Operating Temp:** 0°C to 50°C (commercial, not industrial-rated)
- **Power:** External 12V adapter
- **Cost:** $30-$40 USD

Note: The Netgear GS305E is a **commercial** (not industrial) switch with a narrower operating temperature range. It’s suitable for climate-controlled environments but lacks the ruggedization of the TRENDnet model.

System Architecture for Option 2:

```
                      ┌──────────────────────────┐
                      │   Intel NUC 11 Pro        │
                      │   (Management Node)       │
                      │   - OSC Routing Logic     │
                      │   - Button Interlock      │
                      │   - 2x Ethernet Ports     │
                      └───────┬───────────┬───────┘
                              │           │
                       Port 1 │           │Port 2
                              │           │
            ┌─────────────────┘           └────────────────────────┐
            │                                                      │
            │                                               40m Cat6a STP
            │                                                      │
            │                                                      ▼
      ┌─────▼──────────────────────────────┐          ┌────────────────────┐
      │  TRENDnet TI-PG541i Switch          │          │ Q-SYS Core         │
      │  (5-Port Managed)                   │          │ (192.168.10.50)    │
      │  - DIN rail mounted in rack         │          └────────────────────┘
      │  - Connects 3 plinths               │
      └───┬────────┬────────┬───────────────┘
          │        │        │
       5m │     5m │     5m │
     Cat6 │   Cat6 │   Cat6 │
          │        │        │
      ┌───▼───┐ ┌──▼────┐ ┌─▼─────┐
      │Plinth │ │Plinth │ │Plinth │
      │   1   │ │   2   │ │   3   │
      └───────┘ └───────┘ └───────┘
```

Network Configuration:
- **NUC Port 1** → TRENDnet Switch (uplink)
- **NUC Port 2** → Q-SYS Core (40m direct connection)
- **Switch Port 1** → Plinth 1
- **Switch Port 2** → Plinth 2
- **Switch Port 3** → Plinth 3

- **Switch Port 4** → Unused (spare for expansion)
- **Switch Port 5** → NUC uplink

Rack Mounting for Option 2:
- **1U Rack Shelf:** Middle Atlantic U1 vented shelf
- **Layout:** NUC + TRENDnet switch side-by-side on shelf
- **Combined Dimensions:** 117mm + 144mm = 261mm width (fits easily in 19” / 482mm rack)
- **Total Depth:** 112mm (NUC, deepest component)
- **Cable Management:** 40m cable exits from rear of rack

Total Cost for Option 2:

Component	Cost (USD)
Intel NUC 11 Pro (configured)	$450-$550
TRENDnet TI-PG541i Switch	$150-$200
1U Rack Shelf (Middle Atlantic U1)	$40-$60
Total	**$640-$810**

Budget Alternative (with Netgear GS305E):

Component	Cost (USD)
Intel NUC 11 Pro (configured)	$450-$550
Netgear GS305E Switch	$30-$40
1U Rack Shelf	$40-$60
Total	**$520-$650**

PROS:
- ✅ **Modern processor** - 11th gen Intel with excellent performance
- ✅ **Flexibility** - separate switch can be replaced/upgraded independently
- ✅ **Expandability** - switch provides additional ports for future needs
- ✅ **Managed switch features** - VLAN, QoS, port mirroring for advanced diagnostics
- ✅ **Redundancy option** - if switch fails, can temporarily connect directly to NUC
- ✅ **Spare ports** - switch provides extra ports for expansion
- ✅ **Easy sourcing** - both NUC and switch are widely available

CONS:
- ⚠️ **More components** - two devices instead of one (more points of failure)
- ⚠️ **Higher complexity** - requires switch configuration and management
- ⚠️ **More power** - requires two power supplies (NUC + switch)
- ⚠️ **More expensive** - total cost ~$150-$300 higher than Option 1
- ⚠️ **Fan noise** - Intel NUC has a fan (though quiet)
- ⚠️ **Network topology** - all plinths share switch bandwidth (10Gbps total, more than adequate)

3.2 DETAILED COMPARISON & RECOMMENDATION

Side-by-Side Comparison

Feature	Option 1: Qotom Q355G4	Option 2: NUC + Switch
Total Ethernet Ports	4 native	2 native + 5 on switch = 7 total
Component Count	1 device	2 devices
Rack Space	1U	1U
Total Cost	~$450-$510	~$640-$810 (or $520-$650 budget)
Cooling	Fanless (silent)	Low-noise fan
Power Consumption	36W	90W (NUC) + 20W (switch) = 110W
Processor	Intel i5-5200U (5th gen)	Intel i5-1135G7 (11th gen)
Reliability (MTBF)	>50,000 hours	NUC: 30,000 hours; Switch: >40,000 hours
Complexity	Low (single device)	Medium (two devices, switch config)
Industrial Rating	Yes (0-60°C)	NUC: No (0-50°C); Switch: Yes (-40 to 75°C)
Future Expansion	Limited (4 ports total)	Excellent (7 ports total, 2 spare)
Maintenance	Simple (one device)	More complex (two devices)
Performance	Adequate for OSC routing	Excellent (modern processor)

FINAL RECOMMENDATION: Option 1 (Qotom Q355G4) ⭐

For this 2+ year museum installation, I recommend Option 1 for the following reasons:

1. **Simplicity & Reliability:** Single device = fewer points of failure, critical for 24/7 museum operation
2. **Silent Operation:** Fanless design is ideal for museum environment (no mechanical noise)
3. **Lower Power:** 36W vs 110W saves energy and generates less heat
4. **Cost-Effective:** ~$300 less than Option 2 with managed switch
5. **Proven Platform:** Qotom mini PCs are widely deployed in firewall/networking applications with excellent reliability

6. **Adequate Performance:** OSC routing and button interlock logic are not computationally intensive; the i5-5200U is more than sufficient
7. **Industrial Grade:** Designed for 24/7 operation in commercial/industrial environments

When to Choose Option 2:
- If you need spare Ethernet ports for future expansion
- If you require advanced switch features (VLAN segmentation, port mirroring for diagnostics)
- If maximum processing power is needed (though not required for this application)
- If you want the ability to independently replace/upgrade the switch

3.3 Physical Dimensions for Rack Layout (UPDATED)

For Vendor Rack Layout Planning:

Option 1: Qotom Q355G4 Configuration

Dimension	Measurement (mm)	Measurement (inches)
Total Rack Width	482.6 mm (19” standard)	19.0”
Device Width	187 mm	7.36”
Device Depth	140 mm	5.51”
Device Height	42 mm	1.65”
Rack Height	44.45 mm (1U)	1.75” (1U)
Total Rack Depth Required	200 mm (device + cable clearance)	7.87”
Weight (with shelf)	1.5 kg	3.3 lbs
Mounting Method	Placed on Middle Atlantic U1 vented 1U shelf	

Cable Connections (rear of device):
- 4x RJ45 Ethernet ports (3 for plinths + 1 for Q-SYS)
- 1x DC power jack (12V, external adapter)
- 1x HDMI (for initial setup/diagnostics, optional)

Option 2: NUC + Switch Configuration

Dimension	Measurement (mm)	Measurement (inches)
Total Rack Width	482.6 mm (19” standard)	19.0”
Combined Device Width	261 mm (117 + 144)	10.3” (fits in 19” rack)
Maximum Depth	112 mm (NUC depth)	4.4”
Maximum Height	42 mm (NUC height)	1.65”
Rack Height	44.45 mm (1U)	1.75” (1U)
Total Rack Depth Required	160 mm (devices + cable clearance)	6.3”
Weight (with shelf)	2.0 kg	4.4 lbs
Mounting Method	Both devices placed on Middle Atlantic U1 vented 1U shelf	

Cable Connections:
- NUC: 2x RJ45 Ethernet + 1x DC power
- Switch: 5x RJ45 Ethernet + 1x DC power (or AC adapter)

3.4 Power Requirements (UPDATED)

Option 1: Qotom Q355G4

Component	Voltage	Current	Power
Qotom Q355G4 Mini PC	12V DC	3A	36W
Total	**12V DC**	**3A**	**36W**

Power Supply: External 12V 3A adapter (included with unit)
AC Input: 100-240V AC, 50/60Hz (universal)

Option 2: NUC + Switch

Component	Voltage	Current	Power
Intel NUC 11 Pro	19V DC	4.74A	90W
TRENDnet TI-PG541i Switch	12-52V DC	2A	20W (max)
Total	**Mixed**	**~6.74A**	**110W**

Power Supplies:
- Intel NUC: 19V 90W external adapter (included)
- TRENDnet Switch: 12-52V DC (use 12V 2A adapter) or 100-240V AC adapter

Alternative (Netgear GS305E):
- Netgear: 12V 1A external adapter (12W)
- Total: 90W + 12W = 102W

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4. Wiring Specifications

4.1 Plinth to Management Node (5m runs x 3)

Specification	Details
Cable Type	Cat6 UTP (Unshielded Twisted Pair)
Length	5 meters per cable (3 cables total)
Conductor	23 AWG solid copper (for permanent installation)
Jacket	CMR or CMP rated (for in-wall/plenum installation if required)
Connector	RJ45 modular plugs, factory terminated or field-terminated with keystones
Color Code	T568B wiring standard
Recommended Brand	Belden 2413, Commscope/Systimax, or equivalent
Shielding	Not required at 5m in typical environment, but can use Cat6 F/UTP if EMI is a concern

Why Cat6 UTP at 5m:
- 5 meters is very short; EMI/RFI unlikely to be an issue
- UTP is more flexible and easier to terminate
- Cost-effective
- If plinths are near high-power lighting or motor drives, upgrade to Cat6 F/UTP (foiled)

4.2 Management Node to Q-SYS Server Room (40m run)

Specification	Details
Cable Type	Cat6a S/FTP (Shielded/Foiled Twisted Pair)
Length	40 meters (single continuous run, no splices)
Conductor	23 AWG solid copper
Jacket	CMR or CMP rated (check local fire codes)
Connector	RJ45 shielded modular plugs with metal shells
Color Code	T568B wiring standard
Shielding	S/FTP - overall shield + individual pair foil shields
Grounding	Shield must be grounded at ONE end only (typically at server room) to avoid ground loops
Recommended Brand	Belden 10GXS, Siemon TERA Cat6a, or equivalent
Installation	Use cable tray or conduit; avoid running parallel to AC power cables

Why Cat6a S/FTP at 40m:
- 40m run may pass through walls, above ceiling, near HVAC, lighting, and power distribution
- Shielding protects against EMI/RFI for reliable operation
- Cat6a supports 10 Gigabit Ethernet (future-proofing)
- Critical link to Q-SYS; must be rock-solid reliable

4.3 Power Wiring for Plinths

Specification	Details
Cable Type	3-conductor power cable (Live, Neutral, Ground)
Conductor Size	18 AWG (1.0 mm^2) for low-power devices
Voltage	230V AC (UAE standard) or local voltage
Power Consumption per Plinth	~30W (Raspberry Pi: 15W, LED: 5W, Motor: 10W)
Circuit Protection	Dedicated 5A circuit breaker or fused distribution
Connectors	IEC C13/C14 connector or hardwired to terminal block
Installation	Must comply with UAE electrical codes; installed by licensed electrician

Note: Power is stated as available at each plinth location. Verify with electrical contractor.

4.4 Motor and Sensor Wiring Inside Plinth

Component	Cable Type	Length	Connector
Stepper Motor	4-conductor shielded (if motor cable not supplied)	~1m inside plinth	3-pin JST (per spec) + 4-pin to driver
Button	2-conductor 22-24 AWG	~0.5m	Screw terminal or Molex
Maintenance Switch	2-conductor 22-24 AWG	~0.5m	Screw terminal or Molex
Button LED	2-conductor 22-24 AWG	~0.5m (inside button assembly)	Integrated with button

Wiring Best Practices:
- Use shielded cable for motor wiring to reduce electrical noise
- Keep low-voltage signal wiring separate from motor power wiring
- Use proper strain relief for all connections
- Label all wires clearly

4.5 Cable Management and Installation

- **Cable Trays:** Use metal cable tray or conduit for the 40m run to server room

- **Separation:** Maintain 300mm (12”) separation between data cables and AC power cables
- **Drip Loops:** Install drip loops at entry points to prevent water ingress
- **Labeling:** Label both ends of every cable with unique identifier
- **Testing:** Test all Ethernet cables with cable tester (continuity, wiring map, length) before connecting equipment

---

5. Q-SYS Integration

5.1 Q-SYS Overview

Q-SYS (by QSC) is a software-based audio, video, and control platform commonly used in commercial AV installations. The Q-SYS Core (processor) runs Q-SYS Designer software and provides:

- Audio processing and routing
- Video processing
- Control logic (Lua scripting)
- Network connectivity (built-in Ethernet)
- **Third-party control integration** via TCP/IP, UDP, serial, GPIO

5.2 Recommended Integration Method

Primary Recommendation: OSC over UDP

Parameter	Value
Protocol	OSC (Open Sound Control) over UDP
Port	UDP 5010 (configurable in Q-SYS Designer)
Direction	Bidirectional (Management Node ←→ Q-SYS Core)
Message Format	OSC messages (see Section 1.3)
Q-SYS Implementation	Use Q-SYS “Named Control” with UDP Scripting Component

Why OSC over UDP:
- **Q-SYS Native Support:** Q-SYS Designer has excellent OSC support via Lua scripting
- **Simplicity:** OSC is human-readable and easy to debug
- **Performance:** UDP is low-latency (no TCP handshake overhead)
- **Already Specified:** Your design document mentions “OSC trigger over UDP”
- **Flexibility:** Easy to add new messages without protocol changes

Alternative: TCP/IP Socket Communication

Parameter	Value
Protocol	TCP/IP with custom ASCII commands
Port	TCP 1700 (configurable)
Direction	Bidirectional
Message Format	ASCII strings (e.g., “PLINTH1_BUTTON_PRESS\n”)
Q-SYS Implementation	Use Q-SYS “TCP/IP Client” or “TCP/IP Server” Scripting Component

Why TCP/IP:
- **Guaranteed Delivery:** TCP ensures messages are delivered (vs. UDP’s “fire and forget”)
- **Connection Status:** Can detect if connection is lost
- **Q-SYS Support:** Q-SYS has robust TCP/IP scripting components

Trade-offs:
- TCP has higher overhead (handshake, acknowledgment)
- For button presses, UDP is sufficient (if a button press is missed, user can press again)
- For motor commands, TCP might be preferable (guaranteed delivery)

Recommendation: Start with **OSC over UDP** (as specified in design), but implement connection monitoring and automatic reconnection in management node software.

5.3 Q-SYS Designer Configuration

Step 1: Add Named Controls

In Q-SYS Designer, create Named Controls for each plinth:

- `plinth1_button` (Boolean - button state)
- `plinth1_maintenance` (Boolean - maintenance switch state)
- `plinth1_motor_open` (Boolean - trigger motor open)
- `plinth1_motor_close` (Boolean - trigger motor close)
- `plinth1_led_brightness` (Integer 0-255)

Repeat for `plinth2_` and `plinth3_`.

Step 2: Add UDP Scripting Component

- Drag “Scriptable Controls” component into design
- Configure to listen on UDP port 5010
- Write Lua script to:
- Parse incoming OSC messages
- Update Named Controls
- Send outgoing OSC messages when controls change

Step 3: Integrate with Show Control Logic

- Connect Named Controls to Block Controllers (for audio, video, lighting)
- Example: When `plinth1_button` goes high:

- Disable `plinth2_button` and `plinth3_button` (interlock)
- Trigger audio cue
- Trigger video content on LED ring
- Trigger lighting scene
- Send `plinth1_motor_open` command back to plinth

5.4 Network Configuration

Device	IP Address	Subnet Mask	Gateway
Plinth 1 (SH3-C5)	192.168.10.11	255.255.255.0	192.168.10.1
Plinth 2 (SH3-C6)	192.168.10.12	255.255.255.0	192.168.10.1
Plinth 3 (SH3-C7)	192.168.10.13	255.255.255.0	192.168.10.1
Management Node	192.168.10.1	255.255.255.0	-
Q-SYS Core	192.168.10.50	255.255.255.0	-

Note: If Q-SYS is on existing facility network, use appropriate IP addressing. Consider VLAN segmentation for control network isolation.

5.5 Software Requirements

Management Node Software:

- **Operating System:** Ubuntu Server 22.04 LTS (for mini PC) or Raspberry Pi OS Lite (for RPi)
- **Programming Language:** Python 3.10+ or Node.js 18+
- **Libraries:**
- `python-osc` (for OSC messaging)
- `asyncio` (for concurrent handling of multiple plinths)
- `logging` (for diagnostics)
- **Service Management:** systemd service for automatic startup and restart on failure
- **Monitoring:** Watchdog timer to restart service if it hangs

Plinth Software (Raspberry Pi):

- **Operating System:** Raspberry Pi OS Lite (headless)
- **Programming Language:** Python 3.10+
- **Libraries:**
- `python-osc` (for OSC messaging)
- `RPi.GPIO` or `gpiod` (for GPIO control)
- `pigpio` (for hardware PWM for stepper motor)
- **Service Management:** systemd service
- **Remote Access:** SSH enabled for maintenance

5.6 Middleware Requirements

None Required - Q-SYS and the management node can communicate directly via OSC/UDP or TCP/IP. No additional middleware software (e.g., Crestron control processor, AMX controller) is needed.

Optional Enhancements:
- **MQTT Broker:** For more complex IoT-style messaging (overkill for this project)
- **Node-RED:** Visual programming for message routing (useful for testing and prototyping)

---

6. System Architecture Diagram

```
┌─────────────────────────────────────────────────────────────────────────┐
│                          SERVER ROOM                                    │
│                                                                         │
│  ┌─────────────────────────────────────────────────────────────────┐    │
│  │  Q-SYS CORE PROCESSOR                                           │    │
│  │  ┌─────────────────────────────────┐                            │    │
│  │  │  Q-SYS Designer Software        │                            │    │
│  │  │  - Audio/Video Processing       │                            │    │
│  │  │  - Control Logic (Lua)          │                            │    │
│  │  │  - OSC/UDP Handler (Port 5010)  │                            │    │
│  │  │  - Named Controls               │                            │    │
│  │  └─────────────────────────────────┘                            │    │
│  │            │ ETH (192.168.10.50)                                │    │
│  └────────────┼────────────────────────────────────────────────────┘    │
│               │                                                         │
└───────────────┼─────────────────────────────────────────────────────────┘
                │
                │ 40m Cat6a S/FTP Shielded Ethernet
                │ OSC over UDP (Port 5010)
                │
┌───────────────┼─────────────────────────────────────────────────────────┐
│  LOCAL RACK (Near Exhibition Space)                                     │
│               │                                                         │
│  ┌────────────▼──────────────────────────────────────────────────────┐  │
│  │  MANAGEMENT NODE (1U Rack Mount)                                  │  │
│  │  ┌─────────────────────────────────────────────────┐              │  │
│  │  │  Industrial Mini PC or Raspberry Pi 4           │              │  │
│  │  │  - OSC Message Router                           │              │  │
│  │  │  - Button Interlock Logic                       │              │  │
│  │  │  - Monitoring & Diagnostics                     │              │  │
│  │  │  - IP: 192.168.10.1                             │              │  │
│  │  └─────────────────────────────────────────────────┘              │  │
│  │        │              │              │                            │  │
│  │  ETH0  │        ETH1  │        ETH2  │        ETH3 (to Q-SYS)     │  │
│  └────────┼──────────────┼──────────────┼────────────────────────────┘  │
│           │              │              │                            │  │
│    5m Cat6 UTP    5m Cat6 UTP    5m Cat6 UTP                         │  │
│     OSC/UDP        OSC/UDP        OSC/UDP                            │  │
│           │              │              │                            │  │
└───────────┼──────────────┼──────────────┼───────────────────────────────┘
            │              │              │
            │              │              │
┌───────────▼─────┐  ┌─────▼───────┐  ┌───▼─────────┐
│  PLINTH 1       │  │  PLINTH 2   │  │  PLINTH 3   │
│  (SH3-C5)       │  │  (SH3-C6)   │  │  (SH3-C7)   │
│ ┌─────────────┐ │  │ ┌─────────┐ │  │ ┌─────────┐ │
│ │Raspberry Pi │ │  │ │RasPi 4  │ │  │ │RasPi 4  │ │
│ │Model B 4GB  │ │  │ │4GB      │ │  │ │4GB      │ │
│ │IP:          │ │  │ │IP:      │ │  │ │IP:      │ │
│ │192.168.10   │ │  │ │192.168  │ │  │ │192.168  │ │
│ │    .11      │ │  │ │  .10.12 │ │  │ │  .10.13 │ │
│ └─────────────┘ │  │ └─────────┘ │  │ └─────────┘ │
│   │             │  │   │         │  │   │         │
│   ├─GPIO17──────┼──┤   ├─GPIO17──┼──┤   ├─GPIO17──┤ Button Input
│   ├─GPIO27──────┼──┤   ├─GPIO27──┼──┤   ├─GPIO27──┤ Maint. Switch
│   ├─GPIO22──────┼──┤   ├─GPIO22──┼──┤   ├─GPIO22──┤ LED Control
│   ├─GPIO23──────┼──┤   ├─GPIO23──┼──┤   ├─GPIO23──┤ Motor STEP
│   ├─GPIO24──────┼──┤   ├─GPIO24──┼──┤   ├─GPIO24──┤ Motor DIR
│   └─GPIO25──────┼──┤   └─GPIO25──┼──┤   └─GPIO25──┤ Motor ENABLE
│                 │  │             │  │             │
│ ┌──────────┐    │  │ ┌─────────┐ │  │ ┌─────────┐ │
│ │ TMC2209  │    │  │ │ TMC2209 │ │  │ │ TMC2209 │ │
```

```
│  │ Stepper  │   │ │ Driver   │  │ │ Driver   │  │
│  │ Driver   ├───┼─┤└────┬─────┘  │ │└────┬─────┘  │
│  └────┬─────┘   │ │     │        │ │     │        │
│       │ 3-pin   │ │     │        │ │     │        │
│       │ JST     │ │     │ JST    │ │     │ JST    │
│  ┌────▼─────┐   │ │┌────▼─────┐  │ │┌────▼─────┐  │
│  │ STEPPER  │   │ ││ STEPPER  │  │ ││ STEPPER  │  │
│  │ MOTOR    │   │ ││ MOTOR    │  │ ││ MOTOR    │  │
│  │ (Opens   │   │ ││ (Opens   │  │ ││ (Opens   │  │
│  │ Jewellery│   │ ││ Box)     │  │ ││ Box)     │  │
│  │ Box)     │   │ │└──────────┘  │ │└──────────┘  │
│  └──────────┘   │ └──────────────┘ └──────────────┘
│                 │
│  ┌──────────┐   │ ┌──────────┐    ┌──────────┐
│  │  BUTTON  │   │ │  BUTTON  │    │  BUTTON  │
│  │  with    │◄──┼─┤  with    │◄───┤  with    │
│  │  LED     │   │ │  LED     │    │  LED     │
│  │  Halo    │   │ │  Halo    │    │  Halo    │
│  └──────────┘   │ └──────────┘    └──────────┘
│                 │
│  ┌──────────┐   │ ┌──────────┐    ┌──────────┐
│  │MAINT.    │   │ │MAINT.    │    │MAINT.    │
│  │SWITCH    │◄──┼─┤SWITCH    │◄───┤SWITCH    │
│  │(Contact) │   │ │(Glass    │    │(Glass    │
│  │          │   │ │Detect)   │    │Detect)   │
│  └──────────┘   │ └──────────┘    └──────────┘
│                 │
│  ┌──────────┐   │ ┌──────────┐    ┌──────────┐
│  │ 230V AC  │   │ │ 230V AC  │    │ 230V AC  │
│  │ POWER    │   │ │ POWER    │    │ POWER    │
│  │ (Local)  │   │ │ (Local)  │    │ (Local)  │
│  └──────────┘   │ └──────────┘    └──────────┘
└─────────────────┘
```

Data Flow Example: Button Press Sequence

```
1. User presses button on PLINTH 1
   ↓
2. Raspberry Pi GPIO17 detects button press (falling edge)
   ↓
3. Raspberry Pi sends OSC message: /plinth/1/button/press
   → Management Node (192.168.10.1:5000)
   ↓
4. Management Node receives message, implements interlock logic:
   - Sends OSC to PLINTH 2: /plinth/2/led 0 (turn off LED)
   - Sends OSC to PLINTH 3: /plinth/3/led 0 (turn off LED)
   - Sends OSC to PLINTH 1: /plinth/1/led/pulse (pulse LED)
   ↓
5. Management Node forwards to Q-SYS:
   → OSC message: /plinth/1/button/press
   → Q-SYS Core (192.168.10.50:5010)
   ↓
6. Q-SYS Core receives OSC message:
   - Lua script updates Named Control "plinth1_button" = true
   - Triggers audio cue (AudioFile Player starts)
   - Triggers video content (Media Server starts timeline)
   - Triggers lighting scene (DMX output to lighting)
   - Sends OSC back to Management Node: /plinth/1/motor/open
   ↓
7. Management Node forwards motor command to PLINTH 1:
   → OSC message: /plinth/1/motor/open
   → Raspberry Pi (192.168.10.11:5001)
   ↓
8. PLINTH 1 Raspberry Pi receives command:
   - Activates GPIO23 (STEP) and GPIO24 (DIR) to open jewellery box
   - Stepper motor runs via TMC2209 driver
   - Jewellery box opens smoothly
   ↓
9. After AV content finishes (e.g., 90 seconds):
   Q-SYS sends: /plinth/1/motor/close
   ↓
10. PLINTH 1 closes jewellery box
    ↓
11. Q-SYS sends re-enable commands:
    - /plinth/1/led 255 (LED on)
    - /plinth/2/led 255 (LED on)
    - /plinth/3/led 255 (LED on)
    All buttons are ready for next interaction.
```

7. Bill of Materials (BOM)

7.1 Plinth Components (Quantity: 3 plinths)

Item	Description	Part Number / Model	Qty per Plinth	Qty Total	Unit Price (USD)	Total Price (USD)
1	Raspberry Pi 4 Model B, 4GB RAM	RPI4-MOD-BP-4GB	1	3	$55	$165
2	Industrial microSD Card, 32GB	SanDisk High Endurance SDSQQNR-032G	1	3	$15	$45
3	Raspberry Pi Power Supply, 5V/3A USB-C	Official RPi PSU (SC0218)	1	3	$10	$30
4	TMC2209 Stepper Motor Driver	TMC2209 Module	1	3	$15	$45
5	Stepper Motor Power Supply, 24V/2A	Mean Well HDR-30-24	1	3	$25	$75
6	DIN-rail enclosure for Raspberry Pi	Phoenix Contact EMG 22-B or similar	1	3	$30	$90
7	MOSFET for LED control	IRLZ44N MOSFET	1	3	$1	$3
8	Resistors, connectors, terminal blocks	Assorted	1 set	3	$10	$30
9	3-pin JST connector cable (mo-	Pre-made cable or	1	3	$5	$15

Item	Description	Part Number / Model	Qty per Plinth	Qty Total	Unit Price (USD)	Total Price (USD)
	tor to driver)	connector kit				
10	Cat6 UTP Ethernet Cable, 5m	Factory-terminated patch cable	1	3	$8	$24
				Plinth Subtotal		**$522**

Notes:
- Button (ATS-50975-ENBD-PEARL-MA-ID-0113) is assumed to be provided separately (per drawing reference)
- Stepper motor is assumed to be integrated with jewellery box mechanism (not priced here)
- Maintenance contact switch assumed provided by display case specialist (Goppion)

7.2 Management Node Components (CORRECTED)

Option 1: Qotom Q355G4 (4 Native Ethernet Ports) - RECOMMENDED

Item	Description	Part Number / Model	Qty	Unit Price (USD)	Total Price (USD)
11	Qotom Industrial Mini PC with 4 LAN ports	Q355G4-S02 (i5-5200U, 8GB, 128GB)	1	$420	$420
12	1U Rack Shelf, 19", Vented	Middle Atlantic U1 or Raxxess UNS-1	1	$50	$50
13	Power Supply	Included with Qotom (12V 3A)	1	$0	$0
				Option 1 Subtotal	**$470**

Alternative Model: Protectli Vault VP4650 (Premium Option)

Item	Description	Part Number / Model	Qty	Unit Price (USD)	Total Price (USD)
11a	Protectli Vault 4-port firewall	VP4650 (i5-8250U, 8GB, 120GB)	1	$600	$600
12a	1U Rack Shelf, 19”, Vented	Middle Atlantic U1	1	$50	$50
				Protectli Option Subtotal	**$650**

Option 2: Intel NUC + Managed Switch

Item	Description	Part Number / Model	Qty	Unit Price (USD)	Total Price (USD)
14	Intel NUC 11 Pro	NUC11TNHi5 (configured with 8GB RAM, 256GB SSD)	1	$500	$500
15	Industrial Managed Switch (5-port)	TRENDnet TI-PG541i	1	$175	$175
16	1U Rack Shelf, 19”, Vented	Middle Atlantic U1	1	$50	$50
17	Power Supplies	Included with NUC and Switch	-	$0	$0
				Option 2 Subtotal (Industrial)	**$725**

Budget Alternative for Option 2:

Item	Description	Part Number / Model	Qty	Unit Price (USD)	Total Price (USD)
14a	Intel NUC 11 Pro	NUC11TNHi5 (configured)	1	$500	$500
15a	Managed Switch (5-port, commercial)	Netgear GS305E	1	$35	$35
16a	1U Rack Shelf	Middle Atlantic U1	1	$50	$50
				Option 2 Budget Subtotal	**$585**

7.3 Cabling & Connectivity

Item	Description	Specification	Qty	Unit Price (USD)	Total Price (USD)
15	Cat6a S/FTP Shielded Ethernet Cable	Belden 10GXS or equivalent, 40m	1	$120	$120
16	RJ45 Shielded Connectors	For Cat6a termination (if field-terminated)	2	$5	$10
17	Cable Management	Velcro ties, cable labels	1 set	$20	$20
18	Ethernet Cable Tester	For installation verification	1	$50	$50
				Cabling Subtotal	**$200**

Note: Cat6 UTP cables for plinths (5m x3) already included in Plinth BOM.

7.4 Installation & Miscellaneous

Item	Description	Qty	Unit Price (USD)	Total Price (USD)
19	Rack screws, washers, cage nuts	1 set	$15	$15
20	Network switch (optional)	If using alternative management node	1	$40
21	Backup SD cards	Spare SD cards for Raspberry Pi	5	$15
22	Installation labor (low-voltage cabling)	Estimate for cable pulling & termination	1	$500
			Installation Subtotal	**$630**

7.5 Software & Licensing

Item	Description	Qty	Unit Price (USD)	Total Price (USD)
23	Operating System (Raspberry Pi OS, Ubuntu)	Free and open-source	-	$0
24	Python libraries (python-osc, etc.)	Free and open-source	-	$0
25	Q-SYS Designer Software	Licensed with Q-SYS Core (assumed already owned)	-	$0
26	Custom software development	Python scripts for plinths & mgmt node	-	$2,000
			Software Subtotal	**$2,000**

7.6 Total Bill of Materials Summary (UPDATED WITH CORRECTIONS)

Category	Option	Total Cost (USD)
Plinth Components (x3)	Standard	$522
Management Node	**Option 1: Qotom Q355G4 (RECOMMENDED)**	**$470**
Management Node	Option 1: Protectli Vault VP4650 (Premium)	$650
Management Node	Option 2: NUC + Industrial Switch	$725
Management Node	Option 2: NUC + Commercial Switch (Budget)	$585
Cabling & Connectivity		$200
Installation & Misc		$630
Software Development		$2,000
TOTAL (Option 1: Qotom - RECOMMENDED)		**$3,822**
TOTAL (Option 1: Protectli)		**$4,002**
TOTAL (Option 2: NUC + Industrial Switch)		**$4,077**
TOTAL (Option 2: NUC + Budget Switch)		**$3,937**

Recommendation: Qotom Q355G4 option provides the best value at $3,822 total with maximum reliability for a museum installation.

Notes:
- Prices are approximate and based on November 2025 pricing; verify with suppliers
- **CORRECTION APPLIED:** Previous recommendations incorrectly assumed 2-port mini PCs could be used; corrected to 4-port capable hardware
- Does not include:
- Stepper motors (assumed part of jewellery box mechanism)
- Buttons (specified separately: ATS-50975-ENBD-PEARL-MA-ID-0113)
- Display case maintenance switches (provided by Goppion)
- AC power wiring and electrical work (done by licensed electrician)

- Q-SYS Core hardware (assumed already purchased)
- Software development cost assumes 20-30 hours of programming and testing at $100/hr
- Add 10-15% contingency for unexpected expenses

Cost Comparison:
- **Qotom vs. Previous (Incorrect) Estimate:** ~$65 less, but with correct 4-port capability
- **Most Cost-Effective Solution:** Qotom Q355G4 at $3,822 total
- **Best Performance:** Option 2 with NUC + Industrial Switch at $4,077 (modern processor, expandability)
- **Best Reliability for Museum:** Option 1 with Qotom Q355G4 (fanless, industrial-grade, single device)

---

8. Reliability and Maintenance Considerations

8.1 Reliability Enhancements for 2-Year Operation

Component	Failure Risk	Mitigation Strategy
Raspberry Pi SD Card	HIGH - SD cards can fail in 24/7 operation	Use industrial-grade SD cards (SanDisk High Endurance rated for continuous recording). Alternatively, boot from USB SSD. Keep backup images.
Stepper Motor	MEDIUM - Mechanical wear	Use high-quality stepper motor with rated lifetime > 10,000 open/close cycles. Lubricate mechanism as per manufacturer specs.
Ethernet Cables	LOW - Reliable if properly installed	Use shielded cables for 40m run. Properly terminate and test. Secure connections with locking RJ45 connectors.
Power Supplies	MEDIUM - Can fail if overloaded	Use power supplies with 20-30% headroom. Industrial-grade Mean Well or similar.
Button Contacts	MEDIUM - Mechanical wear	Use high-quality momentary switch rated for > 100,000 actuations.
Software Crashes	MEDIUM - Software bugs	Implement systemd service with automatic restart. Use watchdog timer. Remote monitoring.

8.2 Preventive Maintenance Schedule

Task	Frequency	Responsible Party
Inspect all cable connections	Quarterly	AV Technician
Test button functionality	Monthly	Museum Staff
Check stepper motor operation	Monthly	Museum Staff
Review system logs for errors	Weekly (automated email alerts)	Remote Monitoring
Clean dust from enclosures	Quarterly	Museum Maintenance
Backup SD card images	Before installation, then quarterly	AV Technician
Test maintenance switch	Quarterly	Display Case Specialist
Update software (security patches)	As needed (quarterly check)	AV Technician

8.3 Remote Monitoring and Diagnostics

Implement Remote Access:
- SSH access to all Raspberry Pi units and management node
- VPN or secure remote access via Q-SYS network
- Automated email or SMS alerts for:
- Button press events (for usage analytics)
- Error conditions (motor jams, network disconnections)
- System uptime and health checks

Logging:
- All button presses logged with timestamp
- All motor activations logged
- Network connectivity status logged
- Store logs on management node with 30-day retention

8.4 Spare Parts Inventory

Recommended spare parts to keep on-site:

Item	Quantity	Reason
Raspberry Pi 4 Model B, 4GB	2	Quick replacement if one fails
Industrial microSD Card, 32GB	5	Most likely failure point
TMC2209 Stepper Driver	2	Backup for driver failure
Button (ATS-50975-ENBD-PEARL-MA-ID-0113)	1	Mechanical wear
Cat6 Ethernet Cable, 5m	2	Physical damage
Power Supply, 5V/3A	2	Backup for RPi power
MOSFET (IRLZ44N)	5	Small component, easy to replace

---

9. Installation Process and Timeline

9.1 Installation Phases

Phase	Tasks	Duration	Dependencies
Phase 1: Pre-Installation	• Order all components • Develop and test software • Prepare rack enclosure	3 weeks	None
Phase 2: Plinth Assembly	• Install Raspberry Pi in each plinth • Wire button, switch, motor, LED • Test each plinth standalone	2 days	Plinths physically installed
Phase 3: Cabling	• Pull Cat6 cables from plinths to management node location • Pull Cat6a cable to server room • Terminate and test all cables	3 days	Cable pathways ready
Phase 4: Management Node Setup	• Install management node in rack • Configure network • Load and test software	1 day	Cabling complete
Phase 5: Q-SYS Integration	• Configure Q-SYS Designer • Program Lua scripts • Map Named Controls • Test OSC communication	2 days	Management node online
Phase 6: System Testing	• End-to-end button press testing • Motor synchronization testing • Interlock logic testing • Maintenance mode testing	2 days	All components installed

Phase	Tasks	Duration	Dependencies
Phase 7: Final Commissioning	• Train museum staff • Document system • Handover	1 day	Testing complete
		Total: ~4 weeks	

9.2 Pre-Installation Tasks (Software Development)

Plinth Software (Raspberry Pi):
1. Set up Raspberry Pi OS Lite (headless)
2. Install Python 3.10+ and required libraries (`python-osc`, `RPi.GPIO`, `pigpio`)
3. Develop Python script:
- Read button state (GPIO17) with debouncing
- Read maintenance switch state (GPIO27)
- Send OSC messages on state changes
- Receive OSC messages for motor control and LED control
- Implement stepper motor control (STEP/DIR signals)
- Implement PWM for LED brightness/pulsing
4. Configure systemd service for auto-start
5. Test on bench setup
6. Create SD card image for deployment to all 3 plinths

Management Node Software:
1. Set up operating system (Ubuntu Server or Raspberry Pi OS)
2. Configure network interfaces (4x Ethernet: 3 for plinths, 1 for Q-SYS)
3. Install Python or Node.js
4. Develop message routing software:
- Listen for OSC messages from 3 plinths
- Implement button interlock logic (disable other plinths when one is active)
- Forward messages to Q-SYS
- Receive commands from Q-SYS and route to appropriate plinth
- Logging and error handling
5. Configure systemd service
6. Test with simulated plinths and Q-SYS

Q-SYS Configuration:
1. Add Named Controls for all plinths
2. Create Scriptable Controls component
3. Write Lua script for OSC communication
4. Integrate with audio, video, and lighting cues
5. Test on bench Q-SYS Core (if available) or simulator

9.3 Testing Checklist

- [ ] Each button press sends correct OSC message
- [ ] Button press disables other two buttons (LED off)
- [ ] Pressed button LED pulses
- [ ] Q-SYS receives button press and triggers AV content
- [ ] Motor command from Q-SYS opens jewellery box smoothly

- [ ] Jewellery box opens to 90 degrees and holds position
- [ ] After AV content, motor closes jewellery box
- [ ] All buttons re-enable after sequence completes
- [ ] Maintenance switch detection: when glass is removed, plinth goes offline
- [ ] Maintenance mode: hold button 4 seconds to open, 4 seconds to close
- [ ] Maintenance mode: box stays open during maintenance
- [ ] Network connectivity: if cable is unplugged and reconnected, system recovers
- [ ] Power cycle recovery: if power is lost and restored, system auto-starts
- [ ] Q-SYS reboot: system reconnects after Q-SYS restarts

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10. Risk Analysis and Mitigation

Risk	Probability	Impact	Mitigation
SD card failure	Medium	High (plinth offline)	Use industrial SD cards; keep spare imaged cards on-site; implement remote monitoring
Network cable damage	Low	High (plinth offline)	Use shielded cables; proper cable management; keep spare cables
Stepper motor failure	Low	High (box won't open)	Use quality motor; preventive maintenance; spare motor on-site
Button mechanical failure	Medium	Medium (button unresponsive)	Use high-quality switch rated for >100k actuations; spare button on-site
Software crash	Low	Medium (system restart required)	Systemd auto-restart; watchdog timer; remote monitoring; thorough testing
Q-SYS network issue	Low	High (no show control)	Redundant network path (if budget allows); automatic reconnection logic
Power outage	Low	Low (system auto-recovers)	UPS for management node (optional); systemd auto-start
Visitor misuse	Medium	Low (button held too long)	Implement software timeout; button only active when system is idle

11. Optional Enhancements

Enhancement	Cost	Benefit
PoE (Power over Ethernet) for Plinths	+$150 (PoE injector/switch + PoE HATs)	Single cable to each plinth (power + data), cleaner installation
OLED Status Display on Management Node	+$30	Visual indication of system status without needing SSH access
UPS for Management Node	+$150	Protection against brief power outages
Audio Feedback from Plinths	+$100 (3x small speakers)	Audible click or chime when button is pressed (user feedback)
Usage Analytics Dashboard	+$500 (software dev)	Web dashboard showing button press frequency, peak times, etc.
Backup Management Node	+$535 (or +$185 for RPi)	Hot spare in rack; automatic failover if primary node fails

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12. Vendor and Contact Information

Category	Vendor	Website	Notes
Raspberry Pi	CanaKit, Adafruit, DigiKey	canakit.com, adafruit.com	Authorized distributors
Industrial PC	ASUS, Intel, OnLogic	asus.com, intel.com, onlogic.com	Request quote for PN51 or NUC 11
Stepper Drivers	StepperOnline, Pololu, DigiKey	omc-stepperonline.com, pololu.com	TMC2209 widely available
Cabling	Belden, Commscope, Cable Matters	belden.com, commscope.com	Bulk cable or custom lengths
Rack Hardware	Middle Atlantic, Raxxess, Penn Elcom	middleatlantic.com, raxxess.com	Standard 19” rack components
Power Supplies	Mean Well, TDK-Lambda, DigiKey	meanwell.com, digikey.com	DIN-rail or chassis mount

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13. Summary and Final Recommendations (UPDATED)

⚠️ CRITICAL CORRECTION NOTICE

Issue Identified: The original recommendations suggested hardware (ASUS PN51, Intel NUC) with only 2 native Ethernet ports, which is **insufficient** for this system’s requirement of **4 Ethernet ports** (3 plinths + 1 Q-SYS).

Resolution: Updated recommendations now provide TWO viable options with accurate hardware specifications that meet the 4-port requirement.

13.1 Communication Protocol (UNCHANGED)

- **Plinth ↔ Management Node:** Cat6 UTP Ethernet, 5m, OSC over UDP
- **Management Node ↔ Q-SYS:** Cat6a S/FTP Ethernet, 40m, OSC over UDP or TCP/IP

13.2 Hardware (CORRECTED)

Plinth Hardware (UNCHANGED)

- **Each Plinth:** Raspberry Pi 4 Model B (4GB), TMC2209 stepper driver, industrial SD card
- **Quantity:** 3 plinths

Management Node Hardware (CORRECTED - TWO OPTIONS)

OPTION 1: Qotom Q355G4 Mini PC (RECOMMENDED) ⭐

- **Model:** Qotom Q355G4-S02
- **Processor:** Intel Core i5-5200U (2.2-2.7GHz, dual-core)

- **RAM:** 8GB DDR3L
- **Storage:** 128GB mSATA SSD
- **Ethernet: 4x Native Gigabit LAN ports (Intel i210-AT)**
- **Cooling: Fanless** (silent, no moving parts)
- **Power:** 36W (12V 3A)
- **Dimensions:** 187mm x 140mm x 42mm (7.36” x 5.51” x 1.65”)
- **Operating Temp:** 0-60°C (industrial-grade)
- **Cost:** ~$470 (including rack shelf)

Why Recommended:
- ✅ 4 native Ethernet ports (no adapters needed)
- ✅ Fanless operation (silent for museum environment)
- ✅ Industrial-grade reliability (24/7 operation)
- ✅ Low power (36W)
- ✅ Cost-effective (~$470)
- ✅ Single device (fewer points of failure)

Alternative: Protectli Vault VP4650 (i5-8250U, 4 LAN ports, ~$650) - higher performance but more expensive

OPTION 2: Intel NUC 11 Pro + Managed Switch

- **Mini PC:** Intel NUC11TNHi5 (i5-1135G7, 8GB, 256GB)
- **Switch:** TRENDnet TI-PG541i (5-port managed, industrial) OR Netgear GS305E (5-port, budget)
- **Architecture:** NUC connects to switch for plinths, directly to Q-SYS for show control
- **Power:** 90W (NUC) + 20W (switch) = 110W total
- **Cost:** ~$725 (industrial switch) or ~$585 (budget switch)

When to Choose Option 2:
- Need modern processor performance
- Want spare Ethernet ports for expansion
- Require advanced switch features (VLAN, port mirroring)
- Prefer modular architecture (can replace switch independently)

13.3 Critical Specifications for Vendor (UPDATED)

Management Node Dimensions for Rack Layout:

Option 1: Qotom Q355G4
- **Total Rack Width:** 19 inches (482.6 mm) - standard rack width
- **Device Width:** 187 mm (7.36”) - fits within 19” rack with room
- **Rack Depth Required:** 200 mm (7.87”) - includes device + cable clearance
- **Rack Height:** 1U (44.45 mm / 1.75 inches)
- **Device Height:** 42 mm (1.65”) - fits in 1U with clearance
- **Weight (with shelf):** 1.5 kg (3.3 lbs)
- **Mounting:** Placed on Middle Atlantic U1 vented 1U rack shelf

Option 2: NUC + Switch
- **Total Rack Width:** 19 inches (482.6 mm)
- **Combined Device Width:** 261 mm (10.3”) - both devices side-by-side
- **Rack Depth Required:** 160 mm (6.3”)
- **Rack Height:** 1U (44.45 mm / 1.75 inches)

- **Weight (with shelf):** 2.0 kg (4.4 lbs)
- **Mounting:** Both devices on Middle Atlantic U1 vented shelf

Cable Entry (Both Options):
- **Rear Panel:** 4x RJ45 Ethernet ports (3 for plinths, 1 for Q-SYS)
- **Power:** DC barrel jack (Option 1) or separate DC adapters (Option 2)
- **Optional:** HDMI port for setup/diagnostics

13.4 Cost Estimate (UPDATED)

Configuration	Total System Cost	Breakdown
Option 1: Qotom Q355G4 (RECOMMENDED)	**$3,822**	Plinths $522 + Mgmt $470 + Cabling $200 + Install $630 + Software $2,000
Option 1: Protectli VP4650	**$4,002**	Plinths $522 + Mgmt $650 + other costs
Option 2: NUC + Industrial Switch	**$4,077**	Plinths $522 + Mgmt $725 + other costs
Option 2: NUC + Budget Switch	**$3,937**	Plinths $522 + Mgmt $585 + other costs

Recommended Budget: $4,200-$4,400 (Option 1 + 10-15% contingency)

13.5 Timeline (UNCHANGED)

- **Component Procurement:** 2-3 weeks
- **Software Development:** 2-3 weeks (can overlap with procurement)
- **On-Site Installation:** 1-2 weeks
- **Total Project Duration:** 5-6 weeks from order to commissioning

13.6 Key Success Factors (UPDATED)

1. **Select correct management node hardware** with 4 native Ethernet ports or proper switch configuration
2. **Use industrial-grade SD cards** in all Raspberry Pi units (SanDisk High Endurance)
3. **Properly shield and ground** the 40m Cat6a cable to Q-SYS (use S/FTP shielded)
4. **Thorough testing** of interlock logic and motor control before final deployment
5. **Remote monitoring** setup from day one for proactive maintenance
6. **Spare parts inventory** on-site for rapid replacement
7. **Clear documentation** and training for museum staff
8. **Fanless operation preferred** for silent museum environment (Qotom recommended)

13.7 Vendor Action Items (NEW)

For Rack Layout Planning:
1. **Reserve 1U rack space** for management node
2. **Verify rack depth:** Minimum 200mm (8”) required for Option 1, 160mm (6.3”) for Option 2
3. **Plan cable routing:** 4x Ethernet cables (3x 5m + 1x 40m) from rack to respective locations

4. **Power planning:** Single 12V DC adapter (Option 1) or two adapters (Option 2)
5. **Cooling/Ventilation:** Use vented rack shelf; fanless Qotom generates minimal heat

For Procurement:
- **Primary Recommendation:** Order Qotom Q355G4-S02 from authorized Qotom distributor or Amazon
- **Alternative Sources:** AliExpress, EnjoyGadgets, direct from Qotom China
- **Lead Time:** 2-3 weeks for international shipping if not in stock locally
- **Verify Specifications:** Confirm 4x Gigabit LAN ports before ordering

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14. Next Steps

1. **Review and Approval:** Share this document with stakeholders (AL Tayer Stocks, 2D:3D, JLL, Blue-haus)
2. **Component Selection:** Finalize choice between industrial mini PC vs. Raspberry Pi for management node
3. **Procurement:** Order all components (lead time: 2-3 weeks)
4. **Software Development:** Begin coding and testing plinth and management node software
5. **Q-SYS Programming:** Work with AV integrator to configure Q-SYS Designer
6. **Rack Layout Confirmation:** Provide vendor with management node dimensions (19” x 250-300mm x 1U)
7. **Installation Coordination:** Schedule cabling and installation with on-site teams

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Appendix A: Glossary

Term	Definition
OSC	Open Sound Control - a protocol for communication between computers, synthesizers, and multimedia devices
UDP	User Datagram Protocol - a connectionless network protocol (fast but no guaranteed delivery)
TCP/IP	Transmission Control Protocol/Internet Protocol - connection-oriented (guaranteed delivery)
DMX512	Digital Multiplex - a lighting control protocol (512 channels per universe)
Q-SYS	QSC’s software-based audio, video, and control platform
GPIO	General Purpose Input/Output - programmable pins on Raspberry Pi
PWM	Pulse Width Modulation - technique for controlling LED brightness or motor speed
Stepper Motor	Motor that moves in precise increments (steps) rather than continuous rotation
JST Connector	A type of small connector commonly used for low-voltage devices
Cat6/Cat6a	Category 6/6a Ethernet cable - supports gigabit or 10-gigabit networking
S/FTP	Shielded/Foiled Twisted Pair - Ethernet cable with both overall shield and foil on each pair
RJ45	Registered Jack 45 - standard Ethernet connector
1U	One rack unit - 1.75 inches (44.45mm) of vertical rack space

Appendix B: Raspberry Pi GPIO Pinout Reference

```
Raspberry Pi 4 Model B - 40-pin GPIO Header (Top View)

    3V3  (1) (2)  5V
  GPIO2  (3) (4)  5V
  GPIO3  (5) (6)  GND
  GPIO4  (7) (8)  GPIO14
    GND  (9) (10) GPIO15
 GPIO17 (11) (12) GPIO18
 GPIO27 (13) (14) GND
 GPIO22 (15) (16) GPIO23
    3V3 (17) (18) GPIO24
 GPIO10 (19) (20) GND
  GPIO9 (21) (22) GPIO25
 GPIO11 (23) (24) GPIO8
    GND (25) (26) GPIO7
  GPIO0 (27) (28) GPIO1
  GPIO5 (29) (30) GND
  GPIO6 (31) (32) GPIO12
 GPIO13 (33) (34) GND
 GPIO19 (35) (36) GPIO16
 GPIO26 (37) (38) GPIO20
    GND (39) (40) GPIO21

For this project:
- GPIO17 (pin 11): Button Input
- GPIO27 (pin 13): Maintenance Switch Input
- GPIO22 (pin 15): Button LED PWM Output
- GPIO23 (pin 16): Stepper STEP Signal
- GPIO24 (pin 18): Stepper DIRECTION Signal
- GPIO25 (pin 22): Stepper ENABLE Signal
- GND (pins 6, 9, 14, 20, 25, 30, 34, 39): Common Ground
```

Appendix C: OSC Message Specification

From Plinth to Management Node

Message	Type	Value Range	Description
`/plinth/1/button/press`	Bang	-	Button pressed on plinth 1
`/plinth/1/button/release`	Bang	-	Button released on plinth 1
`/plinth/1/maintenance`	Integer	0 or 1	Maintenance switch state (0=glass on, 1=glass off)
`/plinth/1/status`	String	“ready”, “busy”, “maintenance”	Plinth operational status

(Repeat for `/plinth/2/...` and `/plinth/3/...`)

From Management Node to Plinth

Message	Type	Value Range	Description
`/plinth/1/motor/open`	Bang	-	Command to open jewellery box
`/plinth/1/motor/close`	Bang	-	Command to close jewellery box
`/plinth/1/led`	Integer	0-255	Set LED brightness (0=off, 255=full)
`/plinth/1/led/pulse`	Bang	-	Start pulsing LED effect
`/plinth/1/led/off`	Bang	-	Turn off LED
`/plinth/1/disable`	Bang	-	Disable button (interlock)
`/plinth/1/enable`	Bang	-	Enable button

From Management Node to Q-SYS

Message	Type	Value Range	Description
`/plinth/1/button/press`	Bang	-	Forwarded button press event
`/plinth/1/maintenance`	Integer	0 or 1	Forwarded maintenance status

From Q-SYS to Management Node

Message	Type	Value Range	Description
`/plinth/1/motor/open`	Bang	-	Command to open box (forwarded to plinth)
`/plinth/1/motor/close`	Bang	-	Command to close box
`/system/reset`	Bang	-	Reset all plinths to ready state

Appendix D: Q-SYS Lua Script Example

```lua
-- Q-SYS Control Script for Jewellery Box Interactive
-- Receives OSC messages from Management Node
-- Sends motor commands back to Management Node

-- UDP Configuration
local udp_port_rx = 5010  -- Q-SYS receives on this port
local udp_port_tx = 5011  -- Q-SYS sends to Management Node on this port
local management_node_ip = "192.168.10.1"

-- UDP Socket
udp = require("socket").udp()
udp:setsockname("*", udp_port_rx)
udp:settimeout(0)  -- Non-blocking

-- Named Controls
local plinth1_button = Controls["plinth1_button"]
local plinth1_motor_open = Controls["plinth1_motor_open"]
-- (Define for plinth2, plinth3...)

-- OSC Parser (simplified - use full OSC library in production)
function parseOSC(data)
  -- Extract OSC address and value
  -- Return address, value
  -- (Full implementation needed)
end

-- OSC Sender
function sendOSC(address)
  local msg = address .. "\0"  -- Simplified OSC message
  udp:sendto(msg, management_node_ip, udp_port_tx)
end

-- Main Loop (in Q-SYS Timer or EventHandler)
function checkUDP()
  local data, ip, port = udp:receivefrom()
  if data then
    local address, value = parseOSC(data)

    -- Handle button press
    if address == "/plinth/1/button/press" then
      plinth1_button.Boolean = true
      -- Trigger audio cue
      Controls["audio_cue_1"]:Trigger()
      -- Trigger video
      Controls["media_player_1"].Play = true
      -- Open jewellery box
      sendOSC("/plinth/1/motor/open")
      -- Disable other buttons
      sendOSC("/plinth/2/disable")
      sendOSC("/plinth/3/disable")

      -- After 90 seconds, close box and re-enable
      Timer.CallAfter(function()
        sendOSC("/plinth/1/motor/close")
        sendOSC("/plinth/1/enable")
        sendOSC("/plinth/2/enable")
        sendOSC("/plinth/3/enable")
        plinth1_button.Boolean = false
      end, 90)
    end

    -- (Handle other OSC messages...)
```

```
  end
end

-- Run checkUDP every 50ms
Timer.CallPeriodic(checkUDP, 0.05)
```

END OF DOCUMENT

Document Control:

Version	Date	Author	Changes
1.0	2025-11-03	DeepAgent / AI Analysis	Initial comprehensive technical recommendations

Distribution:
- AL Tayer Stocks (Main Contractor)
- 2D:3D (Subcontractor)
- JLL (Project Management Consultant)
- Bluehaus Group (Lead Consultant/Design Architect)
- Q-SYS Integrator (AV/IT Specialist)

For Questions or Clarifications, Contact:
- Project Technical Team via [project contact information]

This document provides technical recommendations based on the information provided and industry best practices. Final component selection and system design should be verified by qualified engineers and tested in a lab environment before deployment.