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   I. Potential Replacements & Chosen Formwork System
   II. Structural Breadth
   III. Cost and Schedule Impact Analysis

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   I. Research and Feasibility
   II. Cost and Schedule Comparisons
   III. Mechanical Breadth and Conclusion

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Maryland

<table>
<thead>
<tr>
<th>Project Size</th>
<th>$20,000 SF (200,000 SF Parking Garage)</th>
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<tbody>
<tr>
<td>Number of Stories</td>
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<tr>
<td>Contract Value</td>
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<tr>
<td>Estimated Cost-to-Date</td>
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<td>Occupancy Type</td>
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<td>CM at Risk</td>
<td>The James G. Davis Construction Corp.</td>
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<td>Owner/Developer</td>
<td>The JBG Companies</td>
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<tr>
<td>Architect</td>
<td>HOK</td>
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</table>

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Existing Site Plan

Construction Site Plan

Site Logistics Plan - Structure

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**Project Features**

- Concrete batch plant
- Post-tensioned concrete
- Terra cotta rain screen
- Pursuing LEED Silver
Analysis #1 | Integrated Delivery Methods

Problem Statement:
Traditional design-bid-build delivery methods have the potential to hinder the design change approval process.
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    I. Recommendations

Case Studies

Case Study #1
Project comparison

<table>
<thead>
<tr>
<th>Case Study #1 – Project Comparison</th>
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<tbody>
<tr>
<td>Item Description</td>
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<tr>
<td>Contract Value</td>
</tr>
<tr>
<td>Construction Duration</td>
</tr>
<tr>
<td>Construction Work Hours</td>
</tr>
<tr>
<td>Total Labor Cost</td>
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<tr>
<td>Percentage of Total Project Cost</td>
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</table>

Common Themes

Teams  Processes  Risk  Reward  Communication  Documentation  Agreements

Unit cost fluctuations greater with D/B
- D/B - 185 percentage points
- D/B/B - 102 percentage points
Lower D/B labor cost percentage
Early contractor involvement is critical

Case Study #2
Survey of 200+ industry professionals

Success Criteria
- Meeting client’s criteria
- Budget and schedule met
- Reduction in disputes
- Overall quality

Success Factors
- Clearly defined scope
- Good relationships
- Contractor experience
- End user’s early input
- Client participation

Survey Results
- Time/schedule
- Cost
- Quality
- Functionality

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---

**Application to Project**

**Targeted Benefits**

- Early contributions to design
- Reduced design conflicts and RFI’s
- Improved schedule management
- Reduced design documentation time

**Integration Benefits**

<table>
<thead>
<tr>
<th>Benefit Description</th>
<th>Owners</th>
<th>Contractors</th>
<th>Designers</th>
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<tbody>
<tr>
<td>Decreased Life Cycle Costs</td>
<td>☑️</td>
<td>☑️</td>
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<tr>
<td>Ability to Control Desired Outcomes</td>
<td>☑️</td>
<td>☑️</td>
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<tr>
<td>Early Contributions to Design</td>
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<td>☑️</td>
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<td>Improved Budget Management</td>
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<tr>
<td>Reduced Design Conflicts and RFI’s</td>
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<td>☑️</td>
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<tr>
<td>Improved Schedule Management</td>
<td>☑️</td>
<td>☑️</td>
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<tr>
<td>Reduced Design Documentation Time</td>
<td>☑️</td>
<td>☑️</td>
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<tr>
<td>Improved Design Quality</td>
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**Project Delivery Method Comparison**

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<tr>
<th>Item Description</th>
<th>Traditional Delivery Methods</th>
<th>Integrated Delivery Methods</th>
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<tbody>
<tr>
<td>Design Completion During Bid Process</td>
<td>40-70%</td>
<td>80-100%</td>
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<tr>
<td>Early Contractor Involvement</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Team Structure</td>
<td>Separate contracts, “every man for himself”</td>
<td>Partnerships, collaboration</td>
</tr>
<tr>
<td>Risk Management</td>
<td>Individual, transferred when possible</td>
<td>Shared risk, managed together</td>
</tr>
<tr>
<td>Reward for Project Success</td>
<td>Individual incentive</td>
<td>Project success + team reward</td>
</tr>
<tr>
<td>Documentation</td>
<td>Not shared, minimal communication</td>
<td>Shared, open communication</td>
</tr>
<tr>
<td>Technology Use</td>
<td>Minimal</td>
<td>Extensive</td>
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</tbody>
</table>

---

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Conclusion

Integrated Project Delivery Method
- True IPD offers highest level of integration
- Individual success tied directly to project success
- Single multi-party contract not appropriate

Design/Build Delivery Method
- Benefits of integration without single contract
- Co-location of major entities
- Reduces layers of design change approval
- Early contractor involvement
- Full integration not present

Recommended Structure
- Design/build

Design/Build Team
- The JBG Companies
  - Owner/Developer
- GSA
  - Client
- Subcontractors and Suppliers

Analysis 1 | Integrated Delivery
- Overview & Case Studies
- Application to Project
- Conclusion

Analysis 2 | Modular Formwork
- Formwork Systems
- Structural Breadth
- Cost and Schedule
- Mechanical Breadth

Analysis 3 | Terra Cotta
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- Cost and Schedule
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Conclusions and Recommendations

Acknowledgements
Analysis #2 | Modular Concrete Formwork

Problem Statement:
Wood panel post-and-beam formwork is labor intensive and time consuming.
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Desired Benefits

Simple components
Lightweight materials
Rapid reuse cycle
Mobility

Lightweight Formwork Systems

Peri Sky Dock

Aluma Dek

Dokamatic Table

Plywood table panels
DoKart required

Lightweight
Adaptable
Complex components
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Presentation Outline

Structural Breadth

Purpose | Redesign to a Flat Slab System

Largest Column Span

Relocated and Added Columns
**Government Building**

**Maryland**

**Structural Breadth**

**Deflection & Punching Shear**

**ACI 318-11 for calculations**

Two-way slab w/o drop panels

Max span of 30 ft

**ACI Deflection Check**

\[
h > \frac{L}{33} = \frac{30 \text{ ft} * 12}{33} = 10.9 \text{ in}
\]

Minimum slab thickness of 11 in

12 in slab thickness chosen

**ACI Punching Shear Check**

\[
V_u = q_u A = (640 \text{ SF}) * (352 \text{ psf}) = 225,280 \text{ lb}
\]

Allowable shear \( 4*1*0.75\text{ in} = 458,205 \text{ lb} \)

\[
V_u < 0.75 * V_c = 225,280 < 0.75 \times 458,205
\]

225,280 lb < 343,654 lb, punching shear is acceptable
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Cost Analysis

Assumptions

- RSMeans labor costs
  - 65% labor reduction
- Equipment cost +20%

Cost savings calculated for single floor

<table>
<thead>
<tr>
<th>Analysis 1</th>
<th>Integrated Delivery</th>
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<tbody>
<tr>
<td>Cost Analysis</td>
<td></td>
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<tr>
<td>Existing System Costs</td>
<td></td>
</tr>
<tr>
<td>Material (62%)</td>
<td>Labor (35%)</td>
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<tr>
<td>Redesigned System Costs</td>
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<tr>
<td>Material (80%)</td>
<td>Labor (15%)</td>
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</table>

<table>
<thead>
<tr>
<th>Analysis 2</th>
<th>Modular Formwork</th>
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</thead>
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<td>Formwork Systems</td>
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<td>Structural Breadth</td>
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<td>Cost and Schedule</td>
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<td>Mechanical Breadth</td>
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<table>
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<tr>
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<th>Terra Cotta</th>
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<tr>
<td>Overview of Systems</td>
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<tr>
<td>Cost and Schedule</td>
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</tr>
<tr>
<td>Mechanical Breadth</td>
<td></td>
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</tbody>
</table>

VI. Conclusions and Recommendations

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Schedule Analysis and Conclusion

Subsequent Cost Savings
- Roughly four week schedule reduction
- $48,058 per week general conditions costs
- Significant cost savings

<table>
<thead>
<tr>
<th>General Conditions Cost Savings</th>
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<tbody>
<tr>
<td>Cost per Week</td>
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<tr>
<td>$48,058</td>
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</tbody>
</table>

Conclusion
- Concrete redesign enables ideal use of modular formwork
- Peri Sky Deck offers significant cost and time savings
- Labor savings outweigh added material costs
- Schedule reduction applies to the critical path

Roughly four week schedule reduction
- Peri Sky Deck
- General Conditions Reduction

Total Analysis Cost Savings

<table>
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<tr>
<th>Use of Sky Deck Formwork System</th>
<th>$465,742</th>
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<tr>
<td>General Conditions Reduction</td>
<td>$192,232</td>
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Total Cost Savings of Analysis #2: $437,974
Analysis #3 | Terra Cotta Rain Screen Pre-Fabrication

Problem Statement:
The construction of the terra cotta rain screen is complex, involving four layers to be installed consecutively.
Overview of Systems

Current Rain Screen Design

Risk Factors
- Complex process
- Labor intensive
- Time consuming

Components
- Sheathing with z-girts
- Insulation
- Support profile
- Terra cotta panels

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Overview of Systems

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Overview of Systems

Proposed Panel Layout

Panel Sizing

Width: 10'-0" - 17'-6"
Height: 10'-0" - 26'-9"
Total number of panels: 208
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Cost Analysis

<table>
<thead>
<tr>
<th>System</th>
<th>Area (SF)</th>
<th>Cost/SF**</th>
<th>Cost</th>
<th>Combined Cost</th>
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<tbody>
<tr>
<td>Terra Cotta</td>
<td>22,000</td>
<td>$99</td>
<td>$2,171,000</td>
<td>$8,959,500</td>
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<tr>
<td>Glazing</td>
<td>73,500</td>
<td>$93</td>
<td>$6,693,500</td>
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<tr>
<td>Unitized Terra Cotta + Glazing Panels</td>
<td>30,318</td>
<td>$115</td>
<td>$6,631,570</td>
<td>$10,054,496</td>
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<tr>
<td>Remaining Glazing</td>
<td>42,182</td>
<td>$93</td>
<td>$3,922,266</td>
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|                      |           |           |          | **Difference of Combined Scopes vs. Separate Scopes** $1,458,996

Schedule Analysis

<table>
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<tr>
<th>System</th>
<th>Start Date</th>
<th>End Date</th>
<th>Total Duration</th>
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<tr>
<td>Original Terra Cotta</td>
<td>13 Sept 2012</td>
<td>13 Apr 2013</td>
<td>153 days</td>
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<tr>
<td>Unitized Terra Cotta Panels</td>
<td>13 Sept 2012</td>
<td>14 Mar 2013</td>
<td>131 days</td>
</tr>
</tbody>
</table>

Glazing and terra cotta scopes combined under unitized system
- Precast concrete excluded as it does not change
- Square-foot cost data provided by DAVIS and others

Façade Breakdown

- Precast Concrete: 49,000 SF
- Terra Cotta: 22,000 SF
- Glazing: 73,500 SF
- Total Building: 144,500 SF

Schedule Comparison

<table>
<thead>
<tr>
<th>System</th>
<th>Original Terra Cotta</th>
<th>Unitized Terra Cotta Panels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original</td>
<td>Unitized</td>
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<tr>
<td></td>
<td>Sept, Oct, Nov, Dec</td>
<td>Sept, Oct, Nov, Dec</td>
</tr>
<tr>
<td></td>
<td>Jan, Feb, Mar, Apr</td>
<td>Jan, Feb, Mar, Apr</td>
</tr>
</tbody>
</table>

Façade Cost Estimate Data

- Glazing and terra cotta scopes combined under unitized system
- Precast concrete excluded as it does not change
- Square-foot cost data provided by DAVIS and others
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Mechanical Breadth

Breadth Assumptions

Interior:
- RH = 40%
- T = 28°C (82°F) = 297 K

Exterior:
- RH = 80%
- T = -15°C (5°F) = 258 K

Breadth Results

- Relative humidity between layers never exceeds 100%
- Condensation will not occur in this assembly

Building Interiors

<table>
<thead>
<tr>
<th>Material/Layer</th>
<th>P (Pa)</th>
<th>P_e (Pa)</th>
<th>RH (%)</th>
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<tr>
<td>Building Interior</td>
<td>28</td>
<td>3762</td>
<td>1505</td>
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<tr>
<td>Interior Film</td>
<td>25.92</td>
<td>3329</td>
<td>1504.9</td>
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<tr>
<td>Drywall</td>
<td>24.51</td>
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<td>363.7</td>
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<tr>
<td>Air Space</td>
<td>21.37</td>
<td>2962.5</td>
<td>346.3</td>
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<td>Type 4 Insulation</td>
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<td>Air Space</td>
<td>14.27</td>
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<td>Terra Cotta Panel</td>
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<tr>
<td>Exterior Film</td>
<td>-14.00</td>
<td>190.0</td>
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<tr>
<td>Building Exterior</td>
<td>-15.00</td>
<td>190.0</td>
<td>152</td>
</tr>
</tbody>
</table>

Conclusion

A unitized panel system would:
- Create a streamlined process
- Reduce terra cotta installation duration by roughly three weeks
- Mitigate risk of labor and weather variables
- Produce a higher quality end product
- Cost an additional $1,458,996
**Presentation Outline**

**Final Recommendations**

- **Analysis #1 | Integrated Delivery Methods**
  - Design/build better facilitates the design change approval process
  - Co-location of major entities offers ease of communication
  - Early contractor involvement is critical

- **Analysis #2 | Modular Concrete Formwork**
  - Concrete redesign enables ideal use of the Peri Sky Deck
  - Schedule reduction of one month
  - Applies to the critical path
  - Total cost savings of $437,974

- **Analysis #3 | Terra Cotta Rain Screen Pre-Fabrication**
  - Three week schedule reduction
  - Additional cost of $1,458,996
  - More streamlined installation process
  - Factory assembly means improved quality control

**Analysis #1**

- Integrated Delivery Methods
- Design/build better facilitates the design change approval process
- Co-location of major entities offers ease of communication
- Early contractor involvement is critical

**Analysis #2**

- Modular Concrete Formwork
- Concrete redesign enables ideal use of the Peri Sky Deck
- Schedule reduction of one month
- Applies to the critical path
- Total cost savings of $437,974

**Analysis #3**

- Terra Cotta Rain Screen Pre-Fabrication
- Three week schedule reduction
- Additional cost of $1,458,996
- More streamlined installation process
- Factory assembly means improved quality control

**Table**

<table>
<thead>
<tr>
<th>Total Cost Savings</th>
<th>Cost Savings</th>
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<tbody>
<tr>
<td>Use of Sky Deck Formwork System</td>
<td>$269,762</td>
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<tr>
<td>General Conditions Reduction</td>
<td>$169,272</td>
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<tr>
<td><strong>Total Cost Savings of Analysis #2</strong></td>
<td><strong>$437,974</strong></td>
</tr>
</tbody>
</table>
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---

**Acknowledgements**

**Academic Acknowledgements**

Penn State Architectural Engineering Faculty
- Dr. John Messner – CM Advisor
- Ray Sowers – CM Advisor
- Dr. Linda Hanagan – Structural Advisor

**Industry Acknowledgements**

The DAVIS Construction Project Team
- Tyler Moyer – DAVIS Project Manager
- David Gibbons III – DAVIS Senior Project Manager
- Leaha Martynuska – DAVIS Project Manager

PACE Industry Members

Family and Friends
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Appendix
Concrete Systems Cost Estimate

Pre-fabricated Terra Cotta Panel Sizing

<table>
<thead>
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<th>Panel Dimension</th>
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Appendix

Concrete Quantity Take-offs

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<th>Concrete Component</th>
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# Presentation Outline

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   II. Project Features 
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## Appendix

### Concrete Quantity Take-offs

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**Government Building**  
**Maryland**  
**Appendix**  
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