VALUE ADDED OUTCOMES TO OPTIMIZING CONSTRUCTION

A VDC PERSPECTIVE

Ricardo Khan, Mortenson Construction
WHAT IS CONSTRUCTION OPTIMIZATION?

No, It’s not a game...
WHAT IS CONSTRUCTION OPTIMIZATION?

SOME SAY IT IS:

Applying a lean approach and practices to project delivery.

It’s all about maximizing customer value while eliminating waste!

Automation, robotics and moving from builders to assemblers.

Meeting the customer objectives and delivering a project on time and on budget.

When all major design decisions are made early increasing certainty and reducing change

BIM/VDC to drive higher simulation to drive effective planning to build right the first time!

Well, it’s all of the above and then some.
WHAT ARE SOME CHARACTERISTICS & OUTCOMES OF CONSTRUCTION OPTIMIZATION?

- EFFECTIVE COMMUNICATION OF PROJECT TEAM
- COLLABORATIVE / ENVIRONMENT OF TRUST
- EARLY DECISION MAKING
- PROACTIVE vs REACTIVE APPROACH
- HIGH PREFABRICATION / MODULARIZATION
- EFFECTIVE SUPPLY CHAIN
- VIRTUAL PROTOTYPING / SIMULATIONS
- REDUCED REWORK
- REDUCED WASTE
- HIGHER PRODUCTIVITY
- HIGHER QUALITY
- SAFER PROJECT – LESS INJURIES
- REDUCTION IN TIME
- REDUCTION IN COST
- SUPPLY CHAIN OPTIMIZATION
- PROJECT TEAM HAD A GREAT EXPERIENCE
- MOST IMPORTANTLY DELIGHTED CUSTOMER

Again, and then some.
HOW DOES BIM/VDC PLAY A ROLE IN CONSTRUCTION OPTIMIZATION?

MACRO LEVEL: VDC SUCCESS FACTORS & MEASURABLE OUTCOMES

MICRO LEVEL: OPTIMIZATION TO MEET BUSINESS NEED

VDC-DRIVEN OUTCOMES

PREFABRICATION

THE IMPORTANCE OF VIRTUAL DESIGN & CONSTRUCTION

BENEFITS & DRIVERS FOR SUCCESSFUL IMPLEMENTATION

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PURPOSE OF VDC ANALYSIS

WHY?

- DETERMINE VDC SUCCESS FACTORS
- IDENTIFY VDC USE AND OUTCOME RELATIONSHIP
- IDENTIFY KEY PERFORMANCE INDICATORS DRIVEN BY VDC
- COMMONALITIES THAT LED TO HIGH VDC AND PROJECT PERFORMANCE

VDC ANALYSIS RESEARCH THROUGH THE UNIVERSITY OF MINNESOTA – CONSORTIUM OF RESEARCH PRACTICE

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18 PROJECT ANALYSIS
INTEGRATED DELIVERY APPROACH

DELIVERY METHODS:
- DESIGN-BUILD / DESIGN ASSIST / CM-GC @ RISK
- ONE FORMAL IPD PROJECT

WIDE PROJECT COST RANGE: $24M TO $420M

VARIOUS PROJECT TYPES:
- CIVIC
- CULTURAL / MUSEUM
- DATA CENTER
- FEDERAL
- HEALTHCARE / LAB
- OFFICE
- SPORTS

VDC PROJECTS
The 18 case studies analyzed for this report utilize the virtual design and construction process, which is designed to be repeatable, continuously improved and innovative. This approach has been shown to be very consistent in driving project cost and schedule down, mitigating unforeseen circumstances and increasing customer satisfaction.

Mortenson has found that certain activities and project characteristics are key performance indicators of a robust VDC investment. The presence of these indicators on a project has proved to be a reliable way to predict a positive return on the investment made in the VDC process.

Typically, this return is realized in the form of value added to the project by reducing schedule and cost, improving construction quality and ensuring customers get the results they expect.

PROJECTS ANALYZED WITH VIRTUAL DESIGN & CONSTRUCTION

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Completed</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degré 6 Arena</td>
<td>2013</td>
<td>3.3, 16, 18</td>
</tr>
<tr>
<td>Northwest Medical</td>
<td>2013</td>
<td>3.10, 14</td>
</tr>
<tr>
<td>Roy &amp; C. Gary Cadwalader Justice Center</td>
<td>2012</td>
<td>4.11, 11, 16, 61</td>
</tr>
<tr>
<td>The Gates Hospital</td>
<td>2011</td>
<td>4.21</td>
</tr>
<tr>
<td>Harris Health Benefits</td>
<td>2011</td>
<td>7.13</td>
</tr>
<tr>
<td>Center Wingfield Hospital</td>
<td>2011</td>
<td>7.15, 18</td>
</tr>
<tr>
<td>St. Vincent's Hospital</td>
<td>2011</td>
<td>7.15, 18</td>
</tr>
<tr>
<td>Women's Institute for Discovery - Health</td>
<td>2012</td>
<td>7.15, 18</td>
</tr>
<tr>
<td>Cerner Campus</td>
<td>2013</td>
<td>7.15, 18</td>
</tr>
<tr>
<td>Denver Health</td>
<td>2007</td>
<td>7.15, 18</td>
</tr>
<tr>
<td>Edward Jones</td>
<td>2009</td>
<td>4.11, 16</td>
</tr>
<tr>
<td>Tabor Center</td>
<td>2005</td>
<td>4.11, 16, 18</td>
</tr>
<tr>
<td>University of Colorado - Health Science Research Building</td>
<td>2008</td>
<td>7.15, 18</td>
</tr>
<tr>
<td>Paul Chafee Center</td>
<td>2008</td>
<td>7.15, 18</td>
</tr>
<tr>
<td>Horizon Research</td>
<td>2008</td>
<td>7.15, 18</td>
</tr>
<tr>
<td>University of Colorado - Health Science Research Building - Denver Art Museum</td>
<td>2006</td>
<td>7.15, 18</td>
</tr>
</tbody>
</table>

10 OF THE 18 PROJECTS RECEIVED AIA TAP AWARDS
VDC SUCCESS IS DRIVEN BY LEADERSHIP
INTEGRATED DELIVERY APPROACH

INTEGRATED APPROACH & CONSISTENT PROCESS

Gaining the full benefits of VDC requires committing to the process at the beginning of the project and making sure the process is well leveraged throughout the project’s duration.

**PRE-PLANNING**
Develop a project execution plan to set performance expectations and formalize the process and the people.
- Define customer success factors; engage owner
- Define VDC scope to focus on mitigating project risk
- Ensure project team sets performance measures to gauge success
- Utilize an integrated collaborative delivery approach
- Adoption of BIM is driven by leadership
- Project team defines how BIM will be used to improve communication

**DESIGN / PLAN**
Improve communication and collaboration through a 3D virtual model to drive early design decisions that could impact downstream construction processes.
- Build trust through a collaborative approach to project challenges
- Utilize model throughout the project to enhance communication
- Engage the customer to improve decision-making processes
- Implement virtual prototyping on high-risk areas of project
- Employ immersive virtual environments to drive properly timed design decisions
- Integrate the right technology platform to support people and processes

**CONSTRUCTION**
Drive the use of the model into the field by using technology in innovative ways.
- Integrate BIM / VDC into field operations to add value
- Train workforce on technology to support enhanced communication
- Deploy Mobile technology to facilitate project data access and collaboration in the field
- Leverage 4D to drive agility and flexibility into project planning and execution
- Increase certainty through construction system design for self-perform scopes of the work
- Apply digital fabrication and prefabrication strategies
- Leadership support is critical to encourage and drive innovation in the field.

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VDC SUCCESS IS DRIVEN BY LEADERSHIP

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VDC SUCCESS FACTORS

COMMONALITIES ACROSS PROJECTS

1. CONTROLLING RISK BY ENHANCING AGILITY
2. IMPROVING QUALITY - DIGITAL PROTOTYPING
3. THE LAST 100 FEET®
4. ENHANCED DECISION MAKING
**Virtual Design & Construction Results**

**Pre-Planning → Design → Construction**

Direct VDC results on 18 project case studies:

- **600 Total Days** Total Schedule Reductions
- **32 Days** Average Schedule Reduction Due to VDC Process
- **25%** and Greater Productivity Increases
- **2.95%** Average Direct Cost Reductions

**Improving Construction Quality**

Processes* with significant overall impact:

<table>
<thead>
<tr>
<th>Schedule Reduction</th>
<th>Cost Reduction</th>
<th>Productivity Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Coordination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital Fabrication / Prefabrication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction System Design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Review</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase Planning (4D)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D Control &amp; Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing Conditions Modeling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model-Based Estimating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site Utilization Planning</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*2012-14

- **416 Total VDC Projects**
- **52 Dedicated VDC Team Members**
- **+600 VDC Enabled Team Members**
VDC ANALYSIS TAKEAWAYS

1. VDC SCOPE MUST TARGET CUSTOMER/PROJECT OBJECTIVES
2. BIM/VDC IS A VISUAL COMMUNICATION VEHICLE
3. VDC IS A TEAM SPORT – OUTCOMES ARE TEAM BASED
4. VDC PERFORMANCE IS DRIVEN BY LEADERSHIP
5. VDC RELATED KEY PERFORMANCE INDICATORS (KPI)
   - COST / TIME / PRODUCTIVITY / ADOPTION / COLLABORATION – INTEGRATED APPROACH

We are still on our VDC Journey and have a long way to go!
PURPOSE OF CONSTRUCTION OPTIMIZATION

THE BIG WHY?

CUSTOMER BUSINESS OBJECTIVES

- OPERATIONAL REQUIREMENTS
- REGULATORY AGENCIES MANDATE

linear approach would have resulted in a 36-month schedule; however, an overall 18% schedule compression was required.

29.5 MONTHS

36-MONTH CONSTRUCTION SCHEDULE COMPRESSED BY 18%

PREFAB RESEARCH THROUGH THE UNIVERSITY OF COLORADO - BOULDER

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PROJECT OVERVIEW

THE BIG WHY?

PROJECT OVERVIEW
- 831,000+ SF
- 360 INPATIENT PRIVATE BEDS
- 1 CUP + 2 PARKING GARAGES
- MODIFIED IPD w/ COLLABORATION AGREEMENT
PROJECT OVERVIEW VIDEO FROM 2013
PREFABRICATION STRATEGIES SIMPLIFIED

THE WHAT / WHY?

PREFAB SYSTEMS

1. EXTERIOR WALL PANELS
   - CAPITALIZE ON REPETITION
   - OPTIMIZE SCHEDULE
   - OPTIMIZE COST
   - OPTIMIZE QUALITY
   - OPTIMIZE SAFETY
   - OPTIMIZE PEOPLE/PROCESS
   - OPTIMIZE TRADE FLOW

2. BATHROOM PODS

3. MULTI-TRADE RACKS

4. PATIENT HEADWALLS

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PREFABRICATION STRATEGIES SIMPLIFIED
VDC MODEL APPROACH?

Processes with Significant Overall Impact

- Schedule Reduction
- Cost Reduction
- Productivity Increase

3D Coordination
Digital Fabrication / Prefabrication
Construction System Design
Design Review
Phase Planning (4D)
3D Control & Planning
PREFABRICATION KEY PERFORMANCE INDICATORS

WHAT WE MEASURED? PREFABRICATION vs. SITE-BUILT CONSTRUCTION

1. SCHEDULE REDUCTION
2. INDIRECT COST SAVINGS
3. DIRECT COST SAVINGS
4. REDUCTION IN REQUIRED LABOR
5. DIVERTED OFF-SITE LABOR
6. SAFETY INCIDENT REDUCTION
7. JOBSITE PRODUCTIVITY LOSS PREVENTION
## Prefabrication Results

### Exterior Wall Panel Results
Prefabrication vs. Site-Built Construction

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule Reduction</td>
<td>41 Work Days</td>
</tr>
<tr>
<td>Indirect Cost Savings</td>
<td>$2.4 Million</td>
</tr>
<tr>
<td>Direct Cost</td>
<td>3.7% Savings</td>
</tr>
<tr>
<td>Overall Required Labor</td>
<td>5,000 Fewer Hours</td>
</tr>
<tr>
<td>Diverted Labor Off-Site</td>
<td>33,000 Hours</td>
</tr>
<tr>
<td>Reduced Safety Incidents</td>
<td>2 Incidents</td>
</tr>
<tr>
<td>Productivity Enhancement Savings On- and Off-Site</td>
<td>$500,000</td>
</tr>
</tbody>
</table>

**1.74 Benefit-to-Cost Ratio**
## PREFABRICATION RESULTS

### BATHROOM POD RESULTS
Prefabrication vs. Site-Built Construction

<table>
<thead>
<tr>
<th>Metric</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule Reduction</td>
<td>52 Work Days</td>
</tr>
<tr>
<td>Indirect Cost Savings</td>
<td>$3.1 Million</td>
</tr>
<tr>
<td>Direct Cost</td>
<td>4.6% Premium</td>
</tr>
<tr>
<td>Overall Required Labor</td>
<td>27,700 Fewer Hours</td>
</tr>
<tr>
<td>Diverted Labor Off-Site</td>
<td>78,000 Hours</td>
</tr>
<tr>
<td>Reduced Safety Incidents</td>
<td>4 Incidents</td>
</tr>
<tr>
<td>Productivity Enhancement Savings On- and Off-Site</td>
<td>$1.4 Million</td>
</tr>
</tbody>
</table>

**1.29 BENEFIT-TO-COST RATIO**
## PREFABRICATION RESULTS

### MULTI-TRADE RACK RESULTS
Prefabrication vs. Site-Built Construction

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
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<tbody>
<tr>
<td>Schedule Reduction</td>
<td>20 Work Days</td>
</tr>
<tr>
<td>Indirect Cost Savings</td>
<td>$1.2 Million</td>
</tr>
<tr>
<td>Direct Cost</td>
<td>21.7% Premium</td>
</tr>
<tr>
<td>Overall Required Labor</td>
<td>4,700 Additional Hours</td>
</tr>
<tr>
<td>Diverted Labor Off-Site</td>
<td>24,000 Hours</td>
</tr>
<tr>
<td>Reduced Safety Incidents</td>
<td>1 Incident</td>
</tr>
<tr>
<td>Productivity Enhancement Savings On- and Off-Site</td>
<td>$300,000</td>
</tr>
</tbody>
</table>

**1.22** BENEFIT-TO-COST RATIO

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PREFABRICATION RESULTS

PATIENT ROOM HEADWALL RESULTS
Prefabrication vs. Site-Built Construction

<table>
<thead>
<tr>
<th>Category</th>
<th>Comparison</th>
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</thead>
<tbody>
<tr>
<td>Direct Cost</td>
<td>7.6% Premium</td>
</tr>
<tr>
<td>Overall Required Labor</td>
<td>1,300 Fewer Hours</td>
</tr>
<tr>
<td>Diverted Labor Off-Site</td>
<td>16,000 Hours</td>
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<tr>
<td>Reduced Safety Incidents</td>
<td>1 Incident</td>
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<tr>
<td>Productivity Enhancement</td>
<td>Minimum $250,000</td>
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<td>Savings On- and Off-Site</td>
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0.93 BENEFIT-TO-COST RATIO
### TOTAL STUDY RESULTS
Prefabrication vs. Site-Built Construction

<table>
<thead>
<tr>
<th>Category</th>
<th>Result</th>
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</thead>
<tbody>
<tr>
<td>Schedule Reduction</td>
<td>72 Work Days</td>
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<tr>
<td>Indirect Cost Savings</td>
<td>$4.3 Million</td>
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<tr>
<td>Direct Cost</td>
<td>6.0 % Premium</td>
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<tr>
<td>Overall Required Labor</td>
<td>29,500 Fewer Hours</td>
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<tr>
<td>Diverted Labor Off-Site</td>
<td>150,500 Hours</td>
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<tr>
<td>Reduced Safety Incidents</td>
<td>7 Incidents</td>
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<tr>
<td>Productivity Enhancement Savings On- and Off-Site</td>
<td>$2.6 Million</td>
</tr>
<tr>
<td>Benefit-to-Cost Ratio</td>
<td>1.13</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY: RESEARCH STUDY RESULTS

1.13 BENEFIT-TO-COST RATIO

For every dollar spent on prefab, approximately 13% of the investment is expected to be returned as a quantifiable benefit to the project.

EXEMPLA ST. JOSEPH HERITAGE PROJECT

<table>
<thead>
<tr>
<th>PREFAB ELEMENT</th>
<th>SCHEDULE REDUCTION</th>
<th>INDIRECT COST SAVINGS</th>
<th>DIRECT COST</th>
<th>REDUCTION IN REQUIRED LABOR</th>
<th>SAFETY INCIDENTS REDUCED</th>
<th>SAFETY PRODUCTIVITY LOSS PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior Wall Panels</td>
<td>41 Days</td>
<td>$2.4 M</td>
<td>3.7% Savings</td>
<td>5,000 Hours</td>
<td>2</td>
<td>$0.5 M</td>
</tr>
<tr>
<td>Bathroom Pods</td>
<td>52 Days</td>
<td>$3.1 M</td>
<td>4.6% Premium</td>
<td>21,700 Hours</td>
<td>4</td>
<td>$1.4 M</td>
</tr>
<tr>
<td>Multi-Trade Racks</td>
<td>20 Days</td>
<td>$1.2 M</td>
<td>21.7% Premium</td>
<td>N/A</td>
<td>1</td>
<td>$0.4 M</td>
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<tr>
<td>Patient Room Headwalls</td>
<td>0 Days</td>
<td>0</td>
<td>7.6% Premium</td>
<td>1,300 Hours</td>
<td>1</td>
<td>$0.3 M</td>
</tr>
</tbody>
</table>

TOTAL: 72 Days $4.3 M 6.0% Premium 29,500 Hours 150,500 Hours 7 $2.6 M

SCHEDULE & COST CERTAINTY
Commit to an aggressive schedule and budget with more confidence.
18% SCHEDULE COMPRESSION ENABLED 29,500 HOURS OF SAVINGS IN LABOR 6% DIRECT COST PREMIUM

ON-SITE LABOR DENSITY
Improved productivity, flexibility, housekeeping and safety.
$2.6 M JOB PRODUCTIVITY LOSS AVOIDED 150,500 LABOR HOURS DIVERTED OFF-SITE

FEWER SAFETY INCIDENTS
Reduced congestion and schedule demands, improved positions and spaces.
7 SAFETY INCIDENTS AVOIDED

MANPOWER CONSISTENCY
Enhanced efficiency reduces training costs and reinforces cost certainty.
376 HEAD WALLS 346 EXTERIOR WALL PANELS 440 BATHROOM PODS 166 MULTI-TRADE RACKS
HOW DOES BIM/VDC PLAY A ROLE IN CONSTRUCTION OPTIMIZATION?

1. IDENTIFY & RESOLVE ISSUES
2. ANALYZE & SIMULATE SYSTEMS
3. COLLABORATE PROACTIVELY
4. ENHANCE DECISIONS THROUGH VISUAL MEDIUM
5. MODEL IT TWICE VIRTUALLY, BUILD IT RIGHT ONCE
6. VDC IMPROVES SUPPORT OF OUR PEOPLE / PROCESS
7. THE FUTURE STATE OF VDC WILL BE ABOUT PREDICTING PERFORMANCE
CONSTRUCTION OPTIMIZATION IN 2014...

REALITY IS, WE’RE ONLY SEEING THE TIP OF THE ICEBERG!
QUESTIONS?

Download the VDC Analysis Report:
www.mortenson.com/vdc-report

Download the Prefab Study:
www.mortenson.com/prefab

Learn more about Mortenson VDC Journey:
www.mortenson.com/vdc-journey

Mortenson VDC project case studies:
www.mortenson.com/approach/virtual-design-construction/case-studies