اجرا و مدیریت پروژه به روش اصول ناب
(Lean Project Management)

فصل دوم: بکارگیری مفاهیم و اصول روش ناب در مدیریت پروژه

بخش چهارم: یکپارچگی اصول روش ناب با مدلسازی اطلاعات ساختمان (BIM)

ارائه دهندگان:

سید محمدرضا علوی‌پور

(PhD, PMP, CMIT)

کامبیز کردانی

(M.Sc., PMP)

Introduction

Building Information Modelling - BIM & LEAN

What's the Problem?

Where's the Waste?

Where's the Value?

Is this "information"
- Searchable?
- Accessible?
- Accurate?
- Useful?
- Valuable?

Introduction

- New approaches to construction management such as
  - relational contracting and
  - lean design and construction

  are built on a foundation of team integration and open sharing of project-related information.

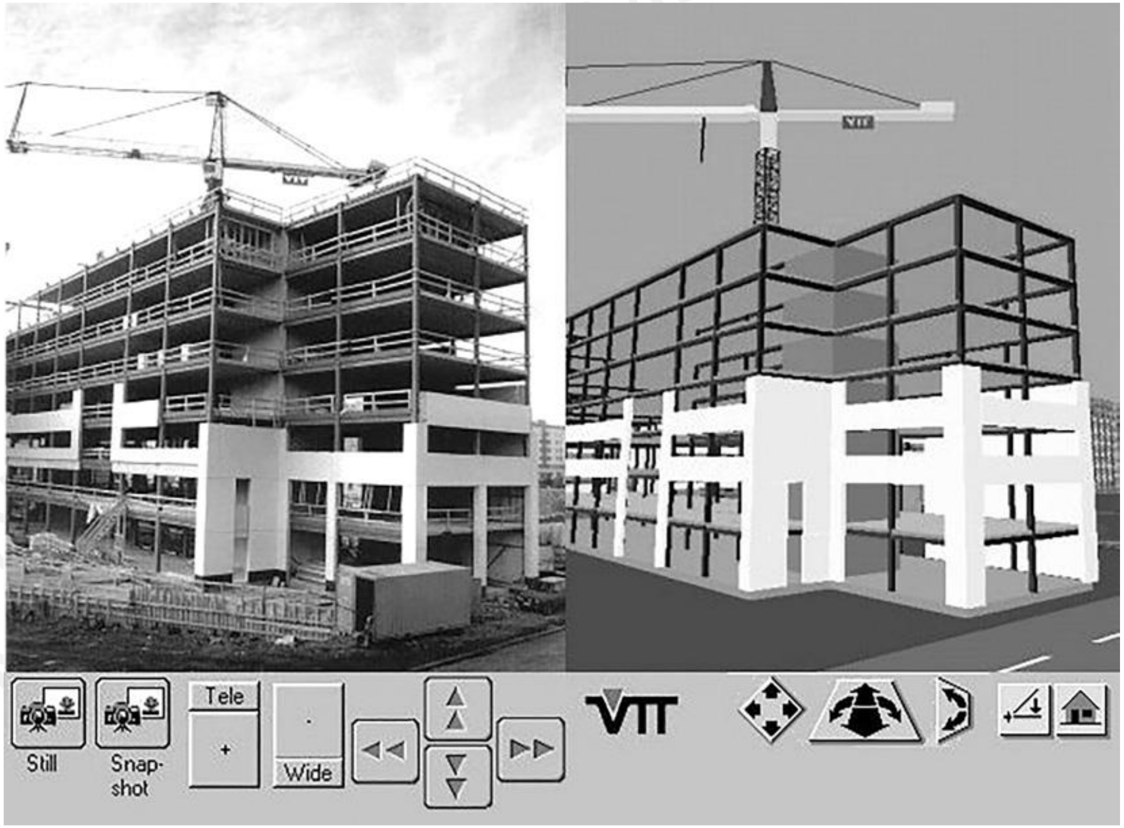
- Information and communication technology (ICT) and building information modeling (BIM) are an **effective** mechanism for providing construction stakeholders with the informational and **analytical tools** for better management of the construction delivery processes.

ICT – a description

- Information and communication technology encompasses computer hardware, software, and communications devices that allow the **sharing and access of information conveniently, locally, and worldwide**.
- The **rapid growth** of the Internet
- Building information modeling is the process of generating and managing building data during its life cycle. It is a tool as well as a **process**, and **increases productivity** and **accuracy in the design and construction** of buildings.

Animated 3-D/4-D visualization concepts

- The core concept of animated 3-D visualizations is to provide a “near-real” replica of the finished product or facility from the basic design to the operation of the facility.



Virtual design studios and concept

- **Virtual design studios** allow designers and experts from different locations to interact using audio and video conferencing.
- **Virtual studios** allow designers to discuss matters related to design or construction without leaving their offices
- The main benefit lies in the fact that experts and designers from any location and at any time can discuss a design issue and propose an immediate solution.

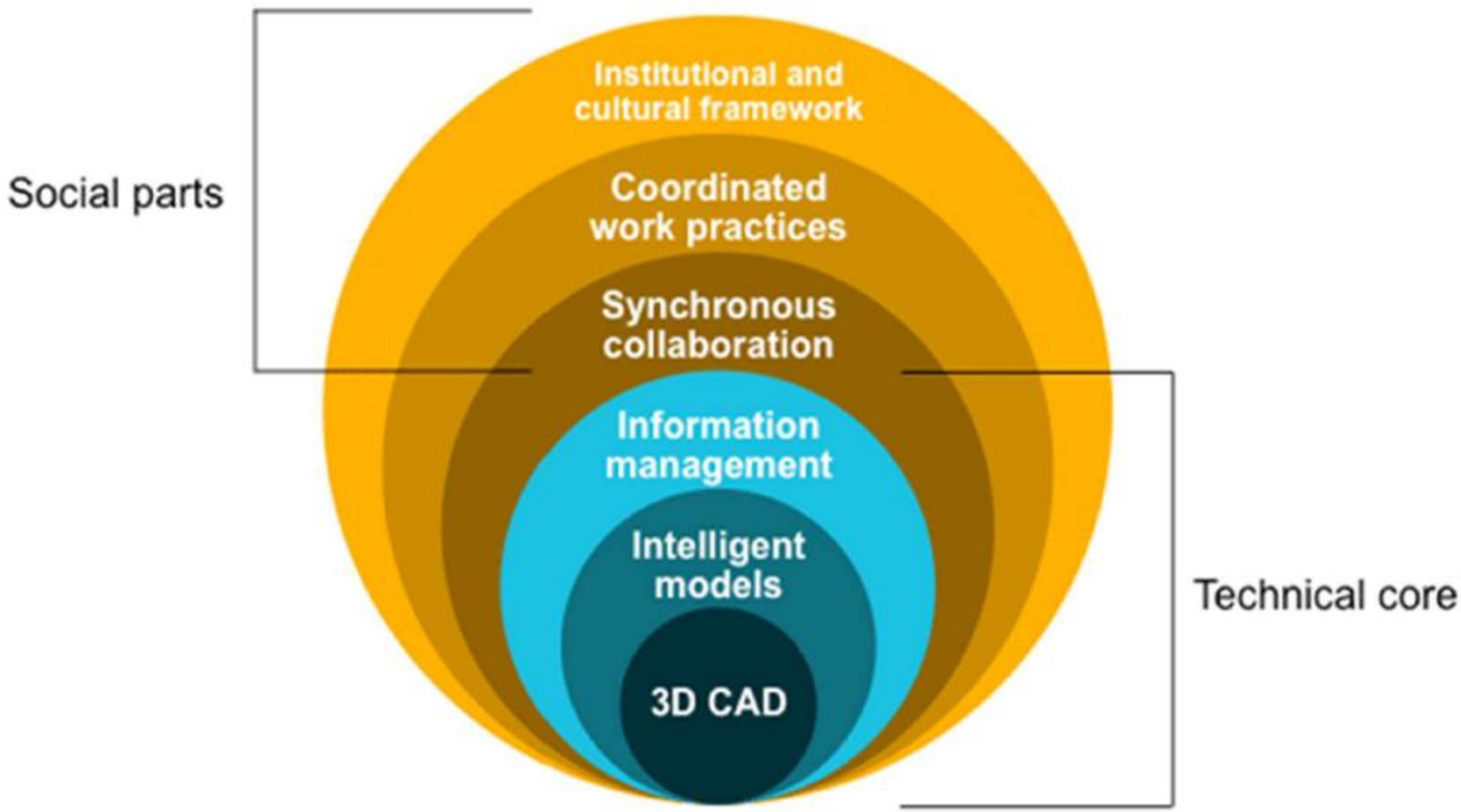
Building information modeling

- **Building information modeling (BIM)** is the process of generating and managing building data during its life cycle.
- The American Institute of Architects (AIA) has defined BIM as

  “a model-based technology linked with a database of project information.”

- A BIM carries all information related to a facility, including its **physical and functional characteristics and project life cycle data,** in a series of “smart objects.”

BIM definition



BIM viewed as a sociotechnical system with a technological base and layers of social components

Process flow for BIM design and construction support

Predesign/ planning phase

Involve the owner, verify the OPR, ensure clarity/completeness. Ensure the appropriateness of the proposed facility design. (Design the “right” facility)
review BOD developed by design team
review scope of equipment and systems

↓

Design phase

Record design options for evaluation
support design for constructability
provide evaluation of design alternatives
cost analysis of alternatives

↓

Construction phase

Support procurement with accurate quantity take-offs
facilitate prefabrication from design information
enable just-in-time procurement
reduce conflicts between trades/disciplines, e.g., structural, electrical, HVAC, plumbing, fire protection
track construction in real time

↓

Acceptance phase

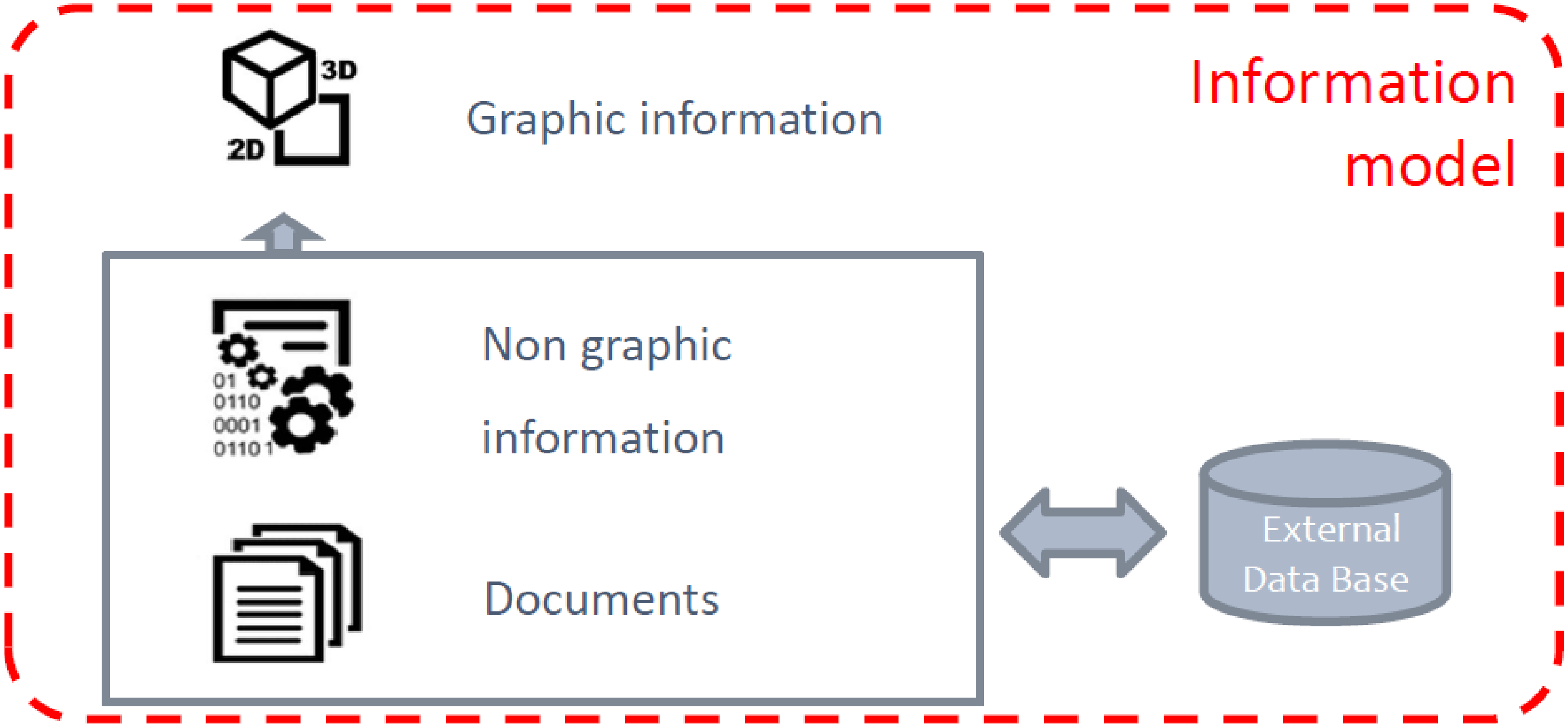
Provide virtual start up to verify system readiness
track/manage documentation of equipment
update “as-builts” for record purposes

↓

Postconstruction/ warranty phase

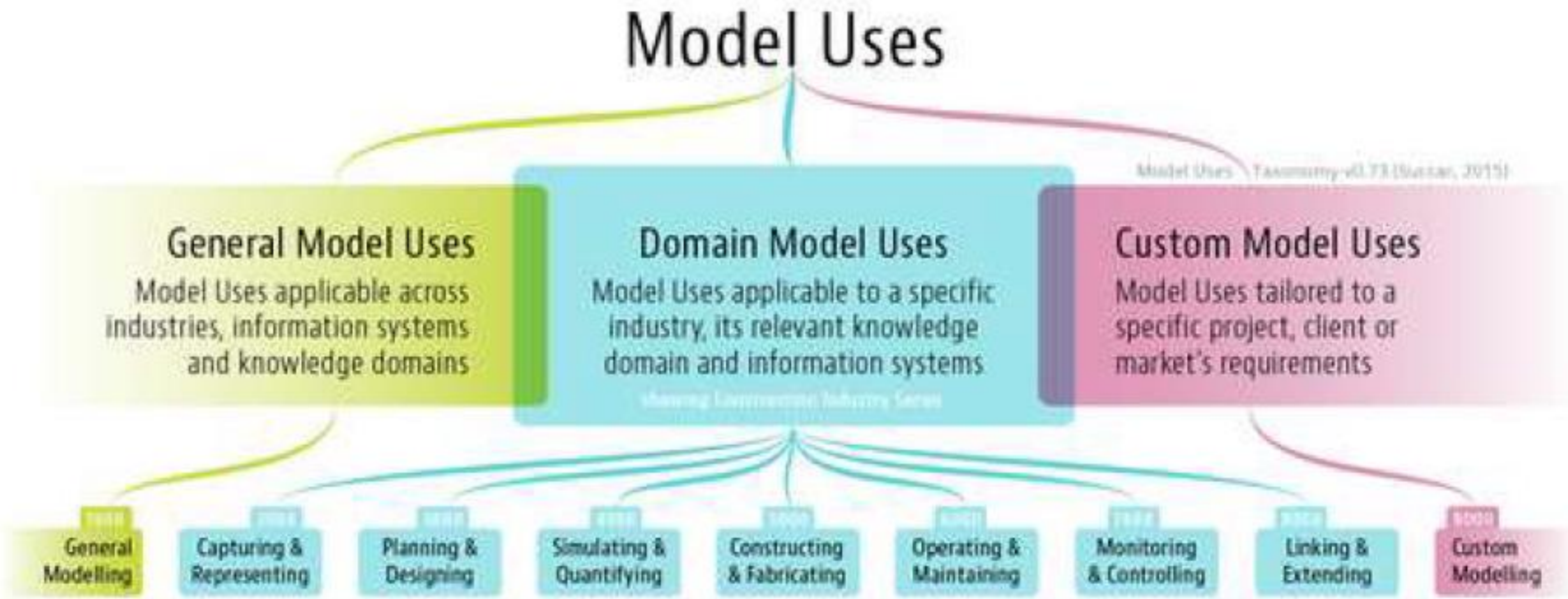
Track facility condition and performance of equipment, energy usage
track tenant/user changes
track warranty issues
track life cycle costs

Characteristics of BIM reference framework



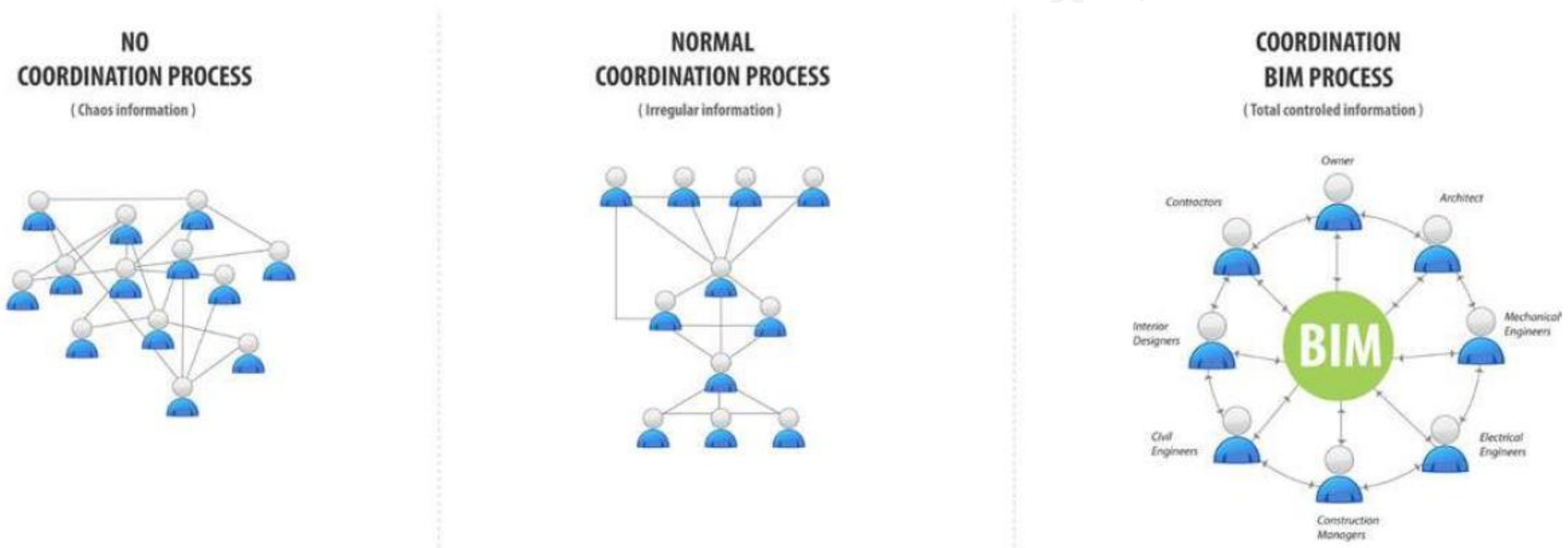
The information needs to be related to the objects in the model

Characteristics of BIM reference framework



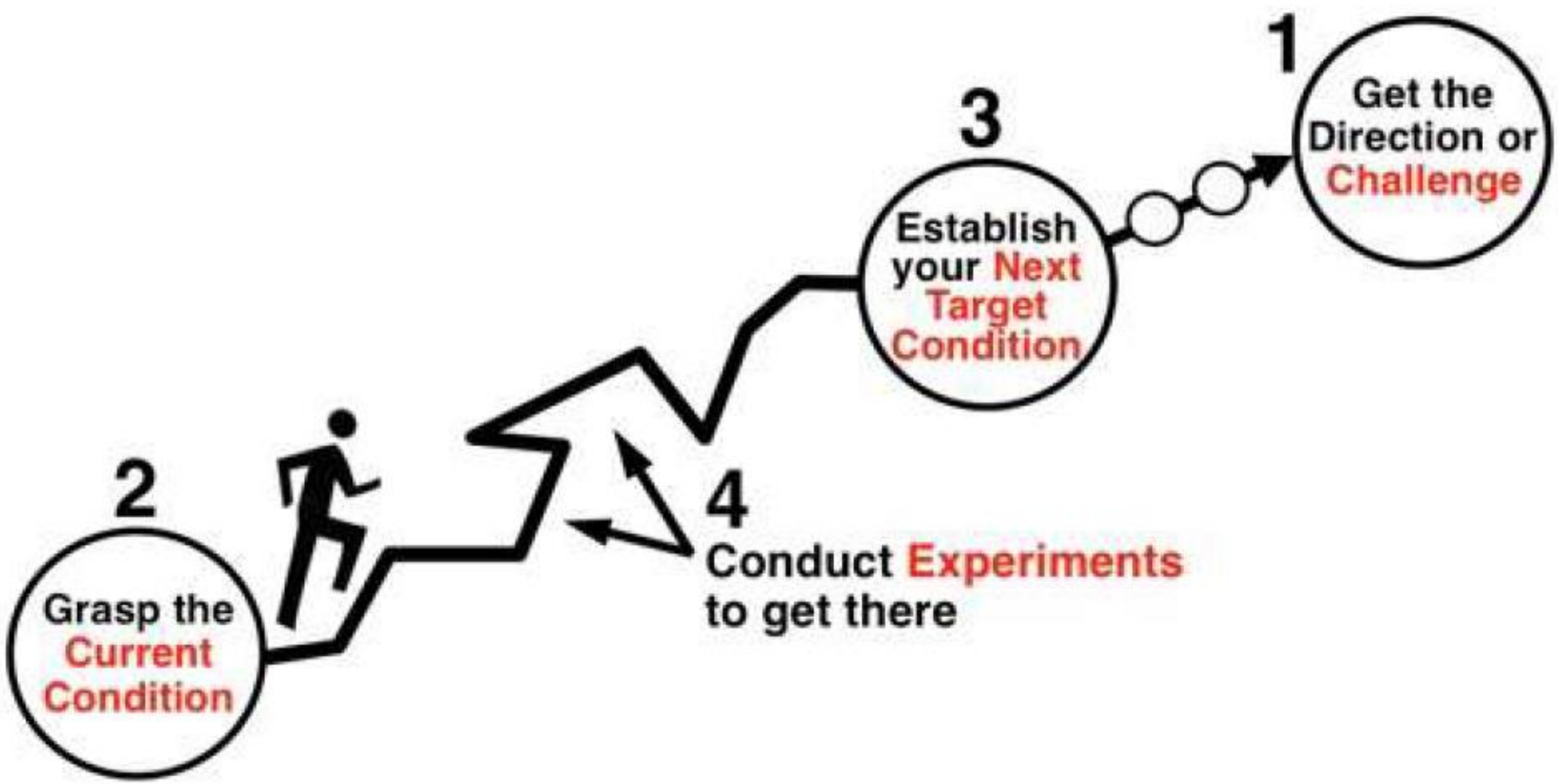
Using object-based models to manage project information

Characteristics of BIM reference framework



Team organization moves from document-centered to data-based

LEAN approach to BIM implementation



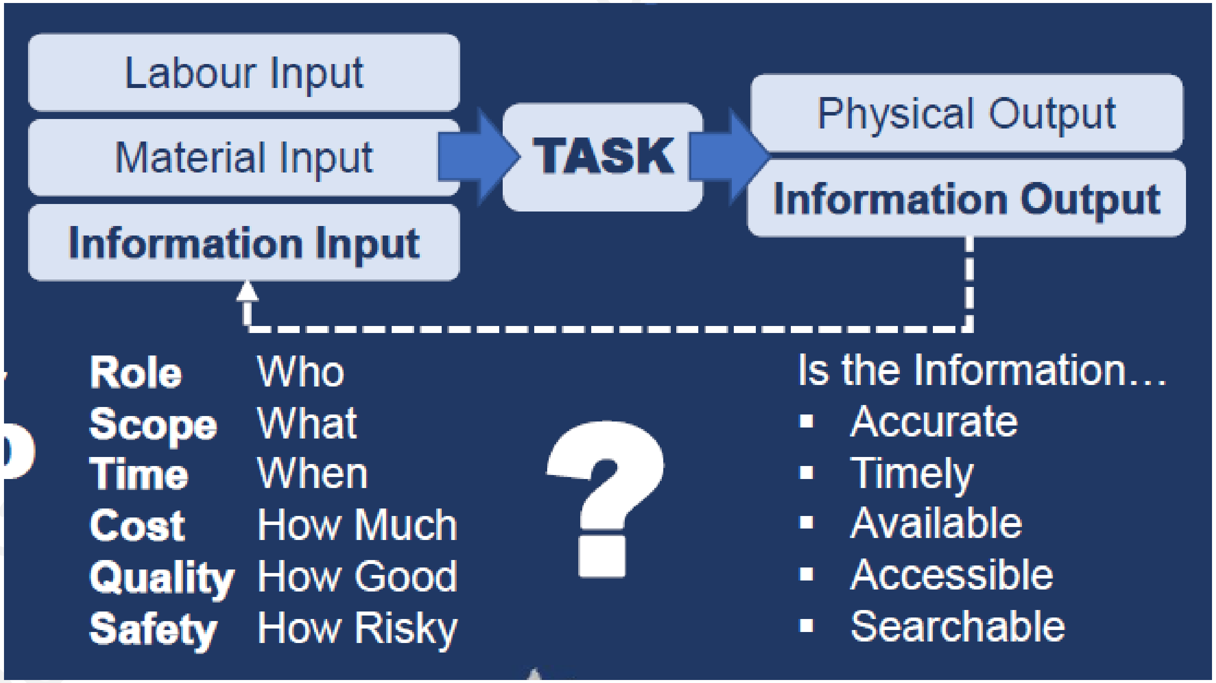
History of BIM

- The term BIM appears to have been adopted by Autodesk to describe "3-D, object-oriented, AEC-specific CAD."
- This medium was rich in architectural information and distinguished from the traditional 2-D drawing.
- Professor Charles M. Eastman at Georgia Institute of Technology has done extensive work on the process starting in the 1970s under the heading of a building product model.

Relationship Between Lean & BIM

- LEAN = Reducing Waste / BIM = Managing Information / Quality of Information & Outcomes

- **Waste "Adds No Value"**
  - **Wasted Time or Effort**
  - **Duplication of Effort**
  - **Abortive Work**
  - **Rework**
  - **Stop-Starting**
  - **Waiting**
  - **Late Engagement**
  - **"Fire Fighting"**
  - **Excessive Contract Administration**
  - **Disputes**
  - **Litigation**



Relationship Between Lean & BIM

Practical applications of BIM

- Visualization: 3-D renderings can be readily generated.
- Fabrication/shop drawings: It is easy to generate shop drawings for various building systems
- Automated Fabrication
- Code reviews
- Forensic analysis
- Facilities management
- Cost estimating
- Construction sequencing
- Conflict, interference and collision detection

Practical applications of BIM

- BIM makes a reliable digital representation of the building available for design decision making, high-quality construction document production, construction planning, performance predictions, and cost estimates.

- BIM provides two major benefits:

  1. **As important design information is kept in digital format, it can be easily updated and shared with all the involved parties.**

  2. **The maintenance of real-time design data in digital form, using parametric building modeling technology, provides major savings of time and money. This leads in turn to an increase in project productivity and quality.**

Economic benefits

- Studies by Stanford University's Center for Integrated Facilities Engineering (CIFE) based on several major projects attribute several savings to the use of BIM: (CIFE 2007)

  1. Up to 40% elimination of unbudgeted change,
  2. Cost estimation accuracy within 3%,
  3. Up to 80% reduction in time taken to generate a cost estimate,
  4. A savings of up to 10% of the contract value through clash detections,
  5. Up to 7% reduction in project time,
  6. An increase in field productivity in the range of 20–30%, and
  7. A tenfold or greater reduction in requests for information (RFIs) and change orders.

Benefits of BIM at each construction project phase

1. Faster delivery speed resulting in time savings.
2. Better design – design proposals can be analyzed in detail, using simulation and other evaluation tools to identify the best solutions.
3. Lower costs, which represents financial savings.
4. Better coordination between different disciplines resulting in fewer errors.
5. Higher work productivity and quality.
6. Provides benefits in the design, construction, and management phases.

Benefits of BIM at each construction project phase

Predesign/ planning phase

Involve the owner, verify the OPR, ensure clarity/completeness. Ensure the appropriateness of the proposed facility design. (Design the “right” facility)
review BOD developed by design team
review scope of equipment and systems

↓

Design phase

Record design options for evaluation
support design for constructability
provide evaluation of design alternatives
cost analysis of alternatives

↓

Construction phase

Support procurement with accurate quantity take-offs
facilitate prefabrication from design information
enable just-in-time procurement
reduce conflicts between trades/disciplines, e.g., structural, electrical, HVAC, plumbing, fire protection
track construction in real time

↓

Acceptance phase

Provide virtual start up to verify system readiness
track/manage documentation of equipment
update “as-builts” for record purposes

↓

Postconstruction/ warranty phase

Track facility condition and performance of equipment, energy usage
track tenant/user changes
track warranty issues
track life cycle costs

Three-dimensional modeling and target cost

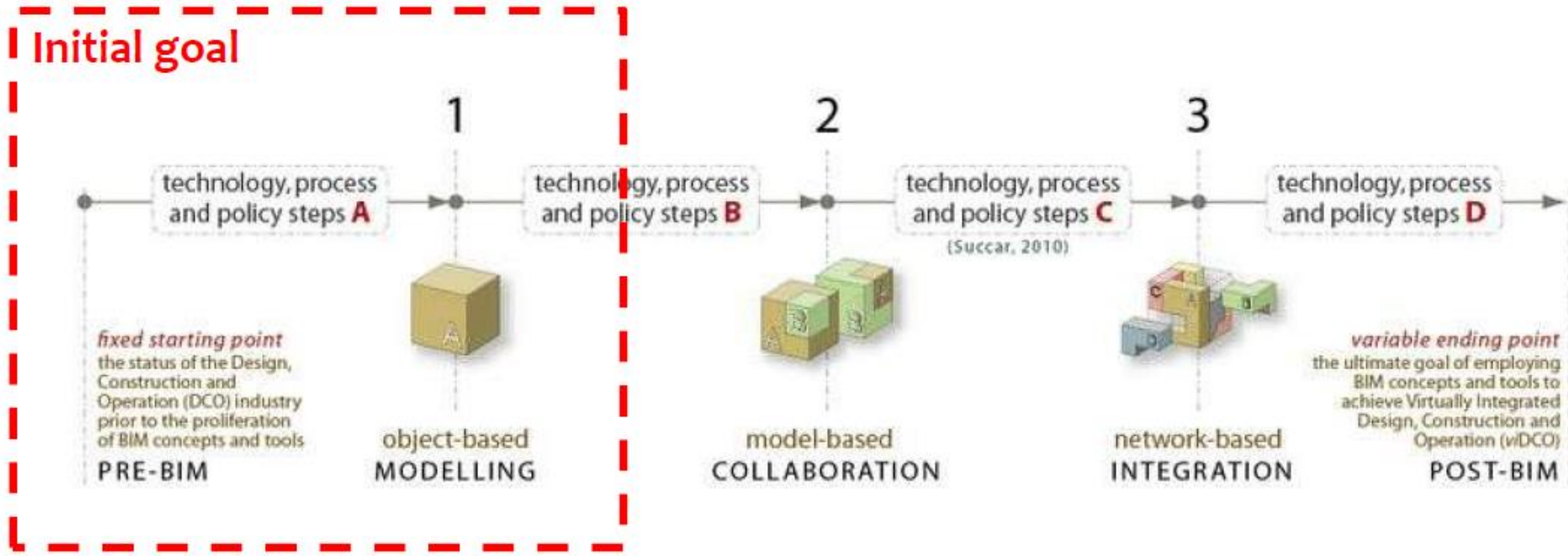
- This modeling supports the target value method of design. As design work progresses, cost estimating **needs to keep pace with the development** of the design.

- Three-dimensional modeling can automatically generate bills of materials, and the associated pricing keeps designers informed of the overall project cost.

- Three-dimensional enabled project delivery features:

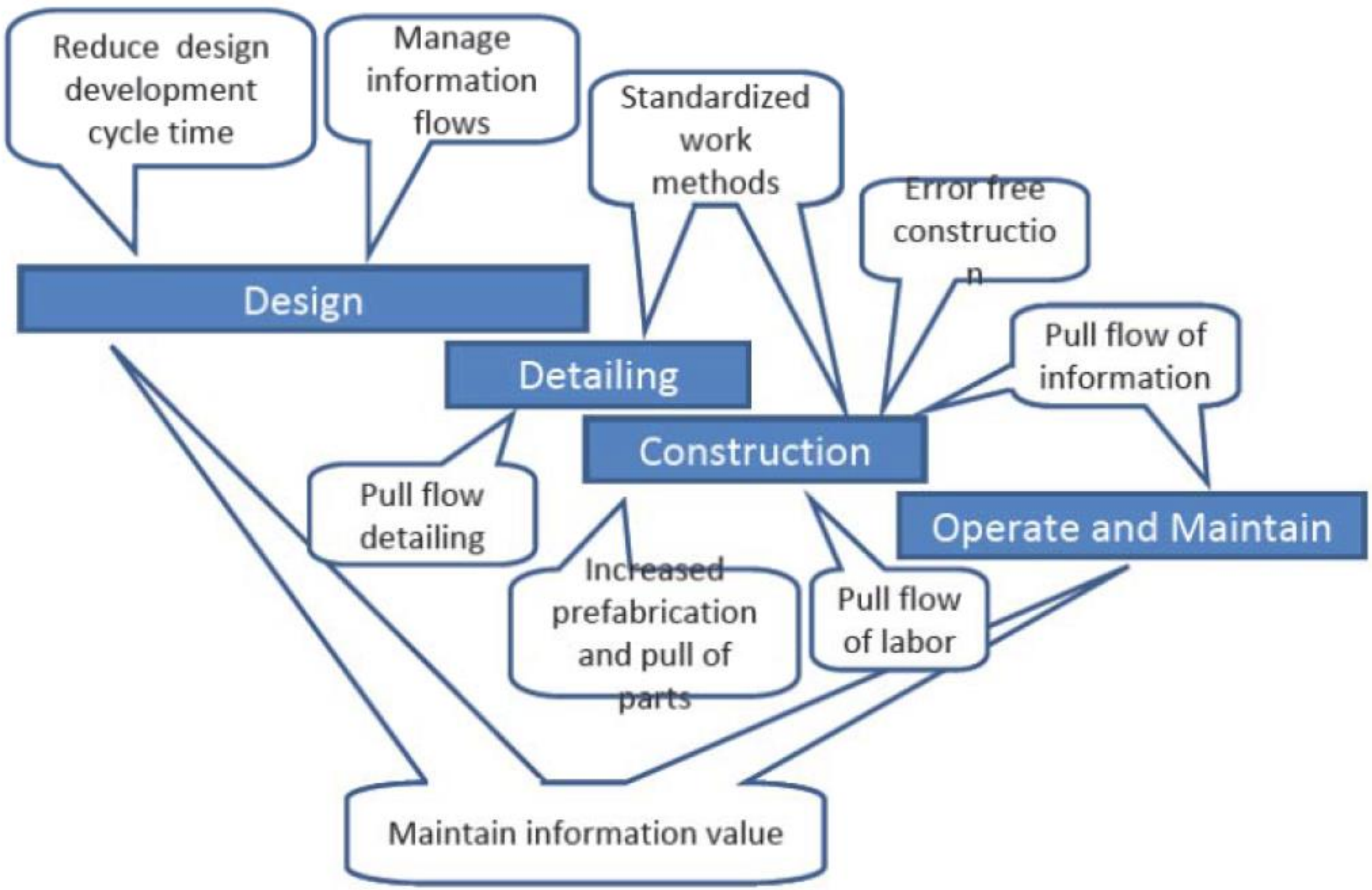
  1. Clash detection
  2. Construction/installation drawings
  3. Procurement (bill of materials)
  4. Structural steel detailing for fabrication

Stages of BIM adoption



Interactions between Lean and BIM

(Borrmann and Rank, 2008)



BIM application in the construction phase

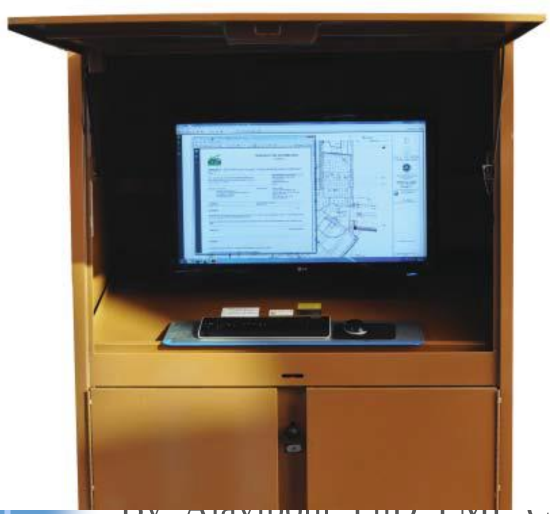
- Constructors can use BIM models to provide much more information than the hard copy construction documents of yesteryear.
- Fewer errors are committed in the interpretation of contract documents, and the interaction of various building systems is checked for clash detection long before installation or erection begins.

BIM kiosks

- According to Hans Thomas Holm of Norway, Head of Project Life Science in Oslo, Statsbygg/Owner Dept.
- BIM kiosks offer great benefits in terms of digital interaction on construction sites.
- A key benefit of BIM kiosks is mobility; it ensures optimum accessibility for all ongoing work in the building.
- As reported by Hans, important lessons were learned from this application:

“Good web access on the construction site is an important prerequisite. Setting up a building site network can be very demanding, and can require significant technical expertise before it works satisfactorily.”

BIM kiosks



BIM during occupancy

- Details of building materials, equipment, systems and “as built” information are readily available through BIM to facilitate the management of a facility for optimum performance.
- Example: Rented space

Case study 1: BIM for the detailed design phase

- Professor Salman Azhar and his research teams of Auburn University, Alabama describe the following to illustrate the cost and time savings available with BIM on an actual construction project.
- **This case study outlines the use of BIM at the detailed design phase.**
- The project is a **$35** million LEED® Silver certified, **110,000 square** academic building on the campus of Emory University in Atlanta, GA.
- It is a **multi-purpose structure** designed to provide instructional and research space and constructed by Holder Construction Company, of Atlanta, GA.

Case study 1: BIM for the detailed design phase

- The project details are as follows:

The project architect developed the building information model of the facility at the early design phase to determine the best building orientation and evaluate various skin options such as masonry, curtain wall and specific window styles.

Case study 1: BIM for the detailed design phase

- The project details are as follows:

The building information model was also used to perform daylight studies, which, in effect, helped to decide the final positioning of the building on the site.

Case study 1: BIM for the detailed design phase

- The project details are as follows:

In order to achieve this, views of the facility were established within a BIM software model using the software's sun positioning feature. Subsequently, the shading and lighting studies, as well as right-to-light studies were conducted in order to determine the effects of the sun throughout the year as well as the effects the proposed facility would have on surrounding buildings.

Case study 1: BIM for the detailed design phase

- The project details are as follows:

Right-to- light studies were also conducted to evaluate lighting conditions at the proposed facility’s courtyard space, and those spaces adjacent to the courtyard.

Case study 1: BIM for the detailed design phase

- As a direct result of these studies, the building's design was adjusted as follows:

1. window openings on the west façade were reduced;
2. the penthouse, which is located on the roof of the building, was reduced in overall square footage; and
3. the overall height of the building was reduced. As all of these design adjustments were able to be incorporated during the design phase, the analyses prevented costly and time-consuming redesign at later stages in the project life cycle (Azhar 2011).

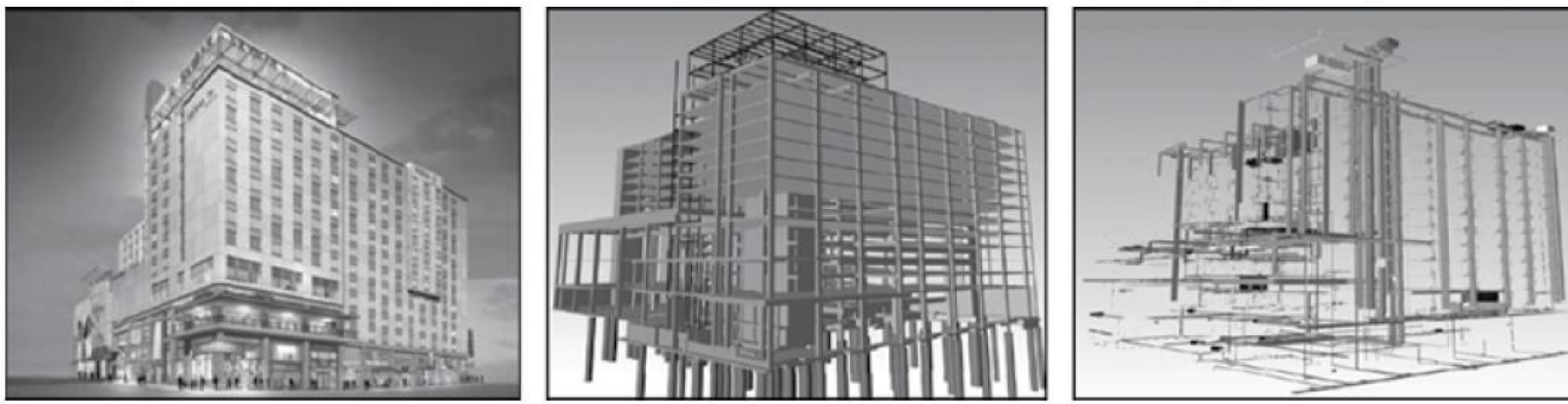
Case study 2: Using BIM with the Hilton Aquarium

- The review teams collaborated with Holder Construction Company, Atlanta, Georgia. (Azhar et al. 2008a, 2008b). The project details are as follows:
  - Project name: Hilton Aquarium, Atlanta, Georgia
  - Project scope: $46M, 484,000 SF hotel and parking structure
  - Delivery method: Construction manager at risk
  - Contract type: Guaranteed maximum price
  - Design assist: GC and subcontractors on board at design definition phase
  - BIM scope: Design coordination, clash detection, and work sequencing
  - File sharing: Navisworks used as common platform
  - BIM cost to project: $90,000, 0.2% of project budget ($40,000 paid by owner)
  - Cost benefit: $600,000 attributed to elimination of clashes
  - Schedule benefit: 1143 hours saved

Case study 2: Using BIM with the Hilton Aquarium

- The contractor created 3-D models of the architectural, structural, and MEP systems of the proposed building. چ

(a) Architectural model (b) Structural model (c) Plumbing model



Case study 2: Using BIM with the Hilton Aquarium

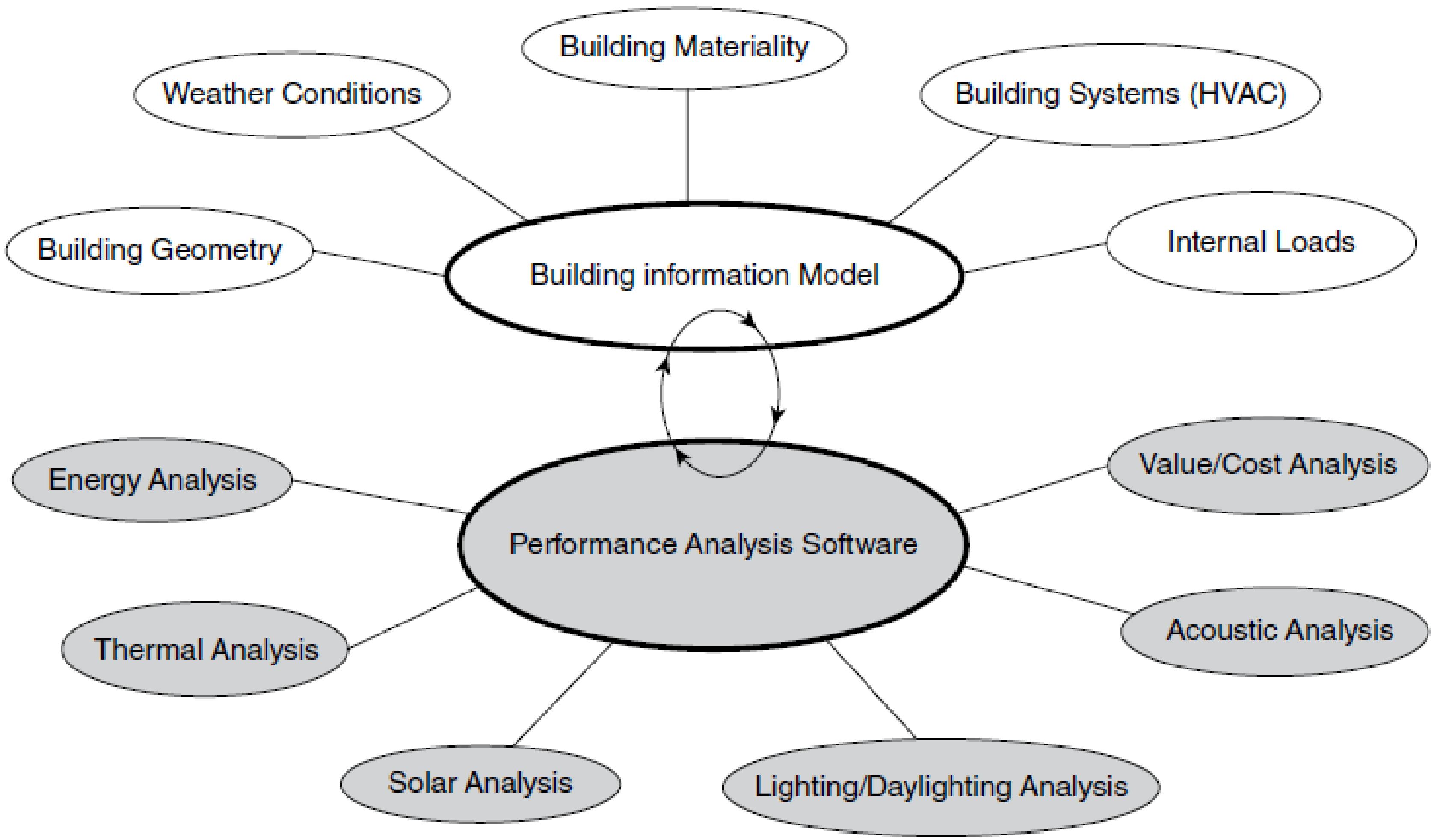
- Using the developed models, the project team achieved the following benefits:

1. Proactively identified 590 conflicts between structural and MEP components and resolved them prior to field installations.
2. Design coordination enhanced.
3. Additional cost increases avoided.
4. Enabled owner to view revisions without issuing change orders.
5. Accommodated design changes.

BIM and lean construction

- BIM supports many initiatives that are critical to lean design and construction.
- Lean design promotes the active participation of construction stakeholders as early as the project definition phase.
- Visualization of form as a BIM functionality enhances Lean principles such as “reduction of variability”, “verification and validation” or “decision by consensus” (Sacks et al. 2010).

Typical information flow in BIM-based building performance analyses



Case Studies

- **Case :Ardmac**

- Ardmac is an international construction specialist delivering complex and high-value workspaces and technical environments.

- Headquartered in Dublin, and with offices in Manchester, Craigavon, and Brussels, Ardmac employs over 300 people and provides specialist services to the commercial fit-out, life sciences, and data centre sectors.

- **Overview & Background to the Lean Initiative:**
  - Ardmac started its journey to adopt Lean, BIM, and other digital technologies in order to streamline workflows and improve productivity. Ardmac leverages technology to support Lean Construction principles.

Case Studies

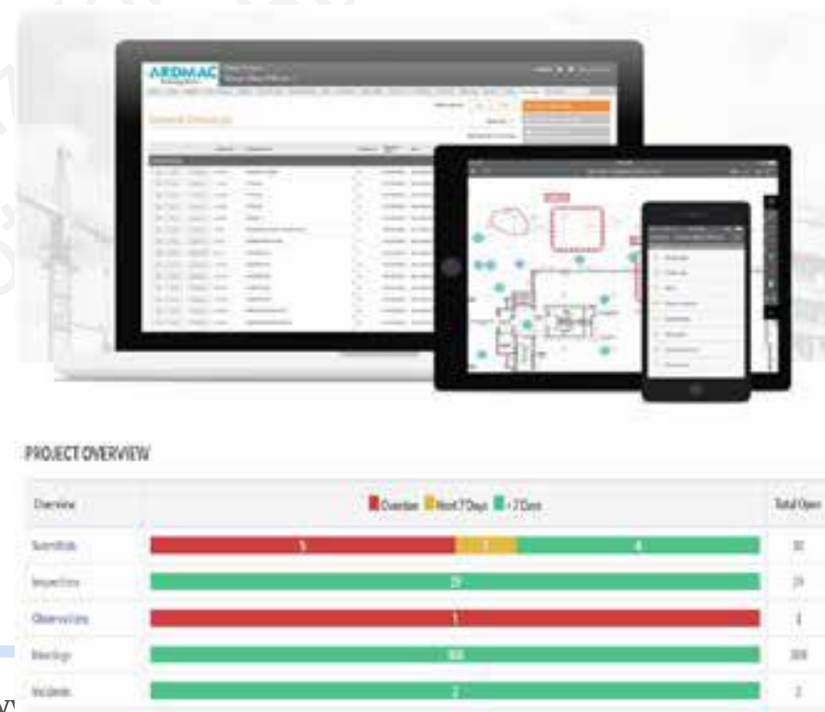
- **Case :Ardmac**

- **Productivity Tracking – Digitally:**
  - The company introduced Lean in 2015, and we have adopted several Lean initiatives across the company since then.
  - They have been particularly successful with the adoption of Last Planner® System (LPS) which allows the proactive sequencing of works and setting of productivity targets.
  - The targets are set using crew size and labour norms, and they are tracked daily and any deviations are monitored.
  - Ardmac has been tracking field productivity for many years, and “Building by Numbers” is the terminology we use across the business as it is a simple and effective concept.

Case Studies

- **Case :Ardmac**

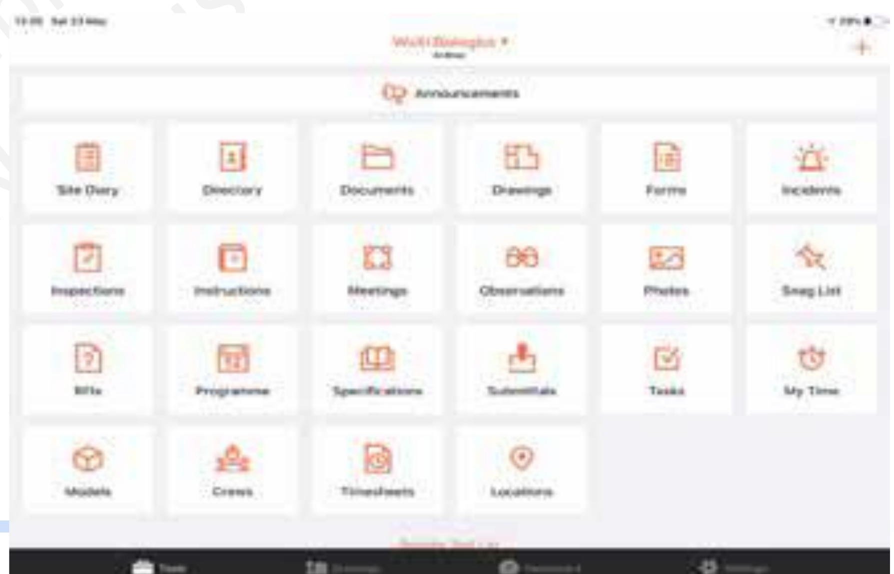
- **Collaboration & Field Management Software:**
  - The use of largely paper-based information is one of several factors that contribute to the lack of efficiency in the construction sector. The traditional siloed approach restricts collaboration by creating barriers between parties to control information flow to mitigate risk for private parties.



Case Studies

- **Case :Ardmac**

- **Collaboration & Field Management Software:**
  - A new collaboration and FMS went live on all projects in February 2019. This provides a central cloud-based platform to share and manage project information
  - there is also a very strong inspection, quality, and safety management aspect to the software which enables the completion of inspections and audits using any mobile device.



Case Studies

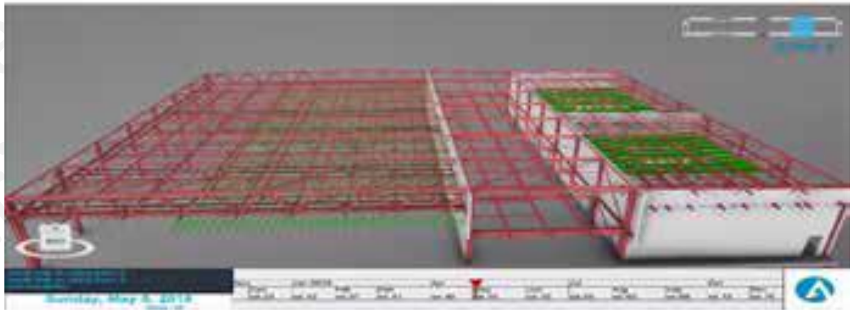
- **Case :Ardmac**

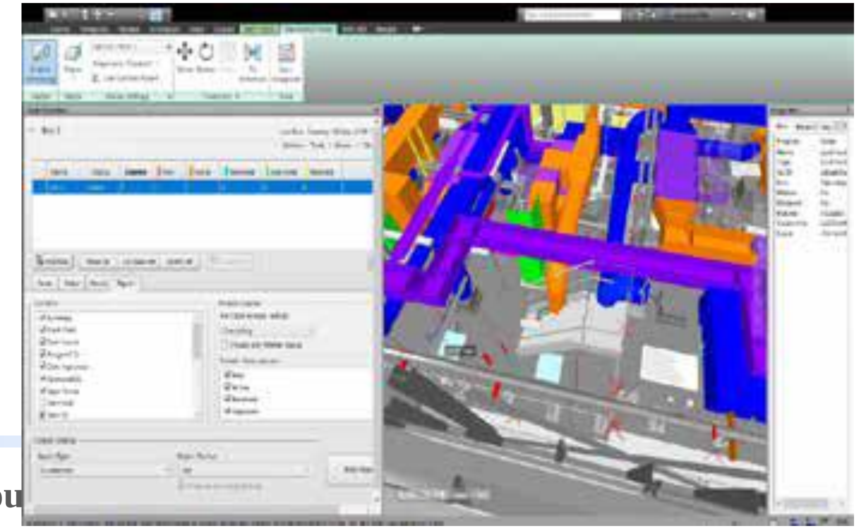
- **RFIs & Observations Linked to Drawings:**
  - Communication among all project teams has become streamlined. Each of the tools on the platform manage a specific part of the project, and all data is controlled via role-based permissions.

Case Studies

- **Case :Ardmac**

- **Building Information Modelling (BIM):**
  - Ardmac has been delivering projects through BIM for over 10 years.

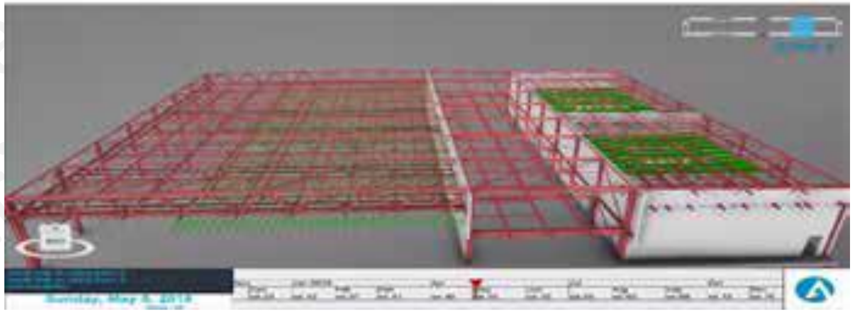


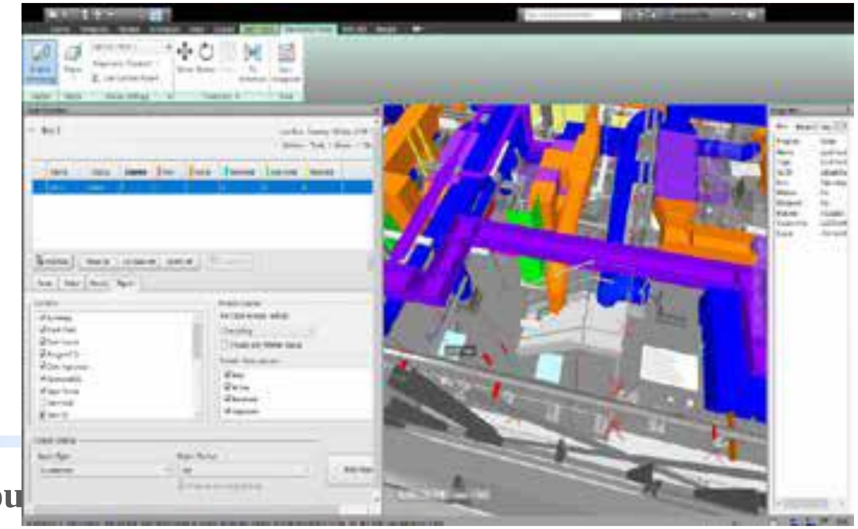


Case Studies

- **Case :Ardmac**

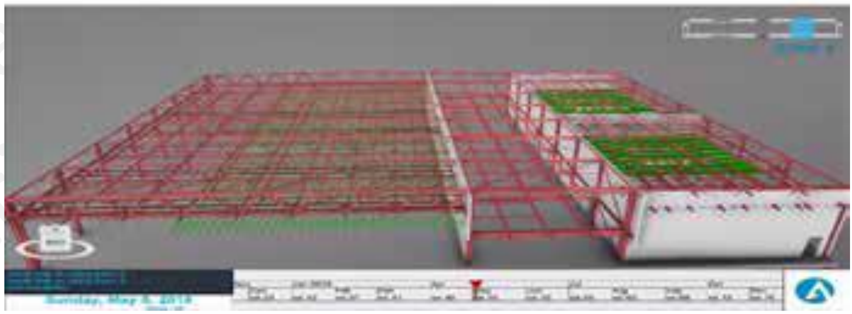
- **Building Information Modelling (BIM):**
  - At first, this started with the creation of 3D models for coordination and clash-detection purposes.

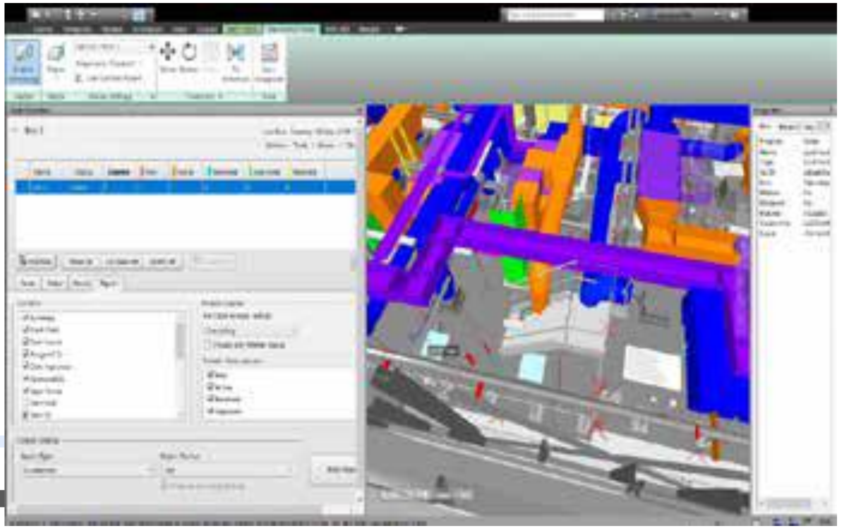




- **Case :Ardmac**

- **Building Information Modelling (BIM):**
  - Over time and through experience and extensive training, BIM capability was increased on projects, including highly detailed and information-rich 3D models up to LOD500. Ardmac has since achieved ISO 19650-2 Certification with BRE, which demonstrates both commitment to BIM excellence and the capability to deliver projects using BIM.





Case Studies

- **Case :Ardmac**

- **Building SMART:**
  - At Ardmac we define Building SMART as combining the three pillars of LPS: our Collaboration, our FMS Platform, and BIM. By implementing these tools and processes on all projects, there is a strong foundation for success.

اجرا و مدیریت پروژه به روش اصول ناب
(Lean Project Management)

فصل دوم: بکارگیری مفاهیم و اصول روش ناب در مدیریت پروژه

بخش پنجم: اندازه گیری عملکرد و میزان پیشرفت پروژه به کمک روش ناب

ارائه دهندگان:

سید محمدرضا علوی‌پور

(PhD, PMP, CMIT)

کامبیز کردانی

(M.Sc., PMP)

Construction progress measurement

- Several methods are proposed for measuring construction performance that include a productivity component:

1. **Units completed**
2. **Incremental milestone**
3. **Start/finish**
4. **Supervisor opinion**
5. **Cost ratio**
6. **Earned value**

Weight	*Subtask*	*Unit*	*Quantity Total*	*Equivalent Steel Tons*	*Quantity To Date*	*Earned Tons*
0.02	Foundation bolts	each	200	1	200	1
0.28	Trusses	each	100	14	50	7
0.30	Columns	each	30	15	20	10
0.20	Beams	each	50	10	30	6
0.20	Roofing-steel deck	square foot	5000	10	1000	2
1.0		Steel	ton	50		26

Note: % complete = Earned tons to date/equivalent tons = 26/50 = 52%.

Productivity estimation based on worth

- Alfeld (1988) equates performance (worth) to the ratio of accomplishment (value) to methods (cost)
- Alfeld developed another measure of performance, i.e., the **"performance ability ratio" (PAR)** as the ratio of exemplar performance to current performance.
- Performance ability ratio (PAR) is calculated as exemplar performance/current performance

Computing PAR values

Reference Code	Gypsum Board Installation (RS Means)	Crew Size (Carpenters)	Work Hours Per Day	Production (Square Feet Per Day)	Exemplar Rate Productivity (Square Feet Per Work Hour)
0150	3/8" wall installation (standard) unfinished	2	16	2000	125
0200	3/8" ceiling installation unfinished	2	16	1800	112.5
0350	V" walls (standard) – taped and finished	2	16	965	60.31
1050	V" ceilings – taped and finished	2	16	765	47.81

	Work Activity	A	B	C = A/B	D	E = D/C	F
Reference Code	Gypsum Board Field Installation	Production (Square Feet) Observed	Work Hours	Productivity Square feet Per Work Hour	Exemplar Rate	PAR Values	Priority for Action
0150	3/8" wall installation (standard) unfinished	2105	32	65.78	125	1.9	1
0200	3/8" ceiling installation unfinished	4153	48	86.52	112.5	1.3	3
0350	V" walls (standard) – taped and finished	689	20	34.45	60.31	1.75	2
1050	V" ceilings – taped and finished	637	16	39.81	47.81	1.2	4

Field ratings

- These are computed as the ratio of people classified as working to the total number of people observed. An adjustment of 10% is added for foreperson and personal time.

Example:

Number of people on site = 120
Number observed = 100
Number noted as working = 50
Percentage working = 50%
Adjusted field rating index = 50% plus 10% = 60%

Labor Utilization Factor (LUF)

The calculation recognizes that work may be effective or essential contributory in nature.

LUF = [effective work + ¼ essential contributory work] / total observed.

Setting up a performance measurement program

- Performance measurement is essential for a construction organization's leaders to gauge performance on a number of selected indicators.
- These indicators provide measurements that serve as a foundation for improvement – as the old adage goes "what gets measured, gets done."

Setting up a performance measurement program

- Performance measurement systems should track several factors representing components of organizational performance such as:
  - productivity indices,
  - quality measurements,
  - safety measurements,
  - schedule compliance,
  - budget compliance.

Setting up a performance measurement program

- Improvement can be achieved by a variety of initiatives that include lean construction, total quality management (TQM), six sigma, and ISO 9001:2000.
- While most organizations have systems that keep track of financial performance, construction productivity calls for a number of specific measures. They include:
  - Labor productivity
  - Crew productivity
  - Exemplar rates
  - PAR (performance ability ratio)
  - Nonproductive time
  - Safety performance
  - Lost time accidents

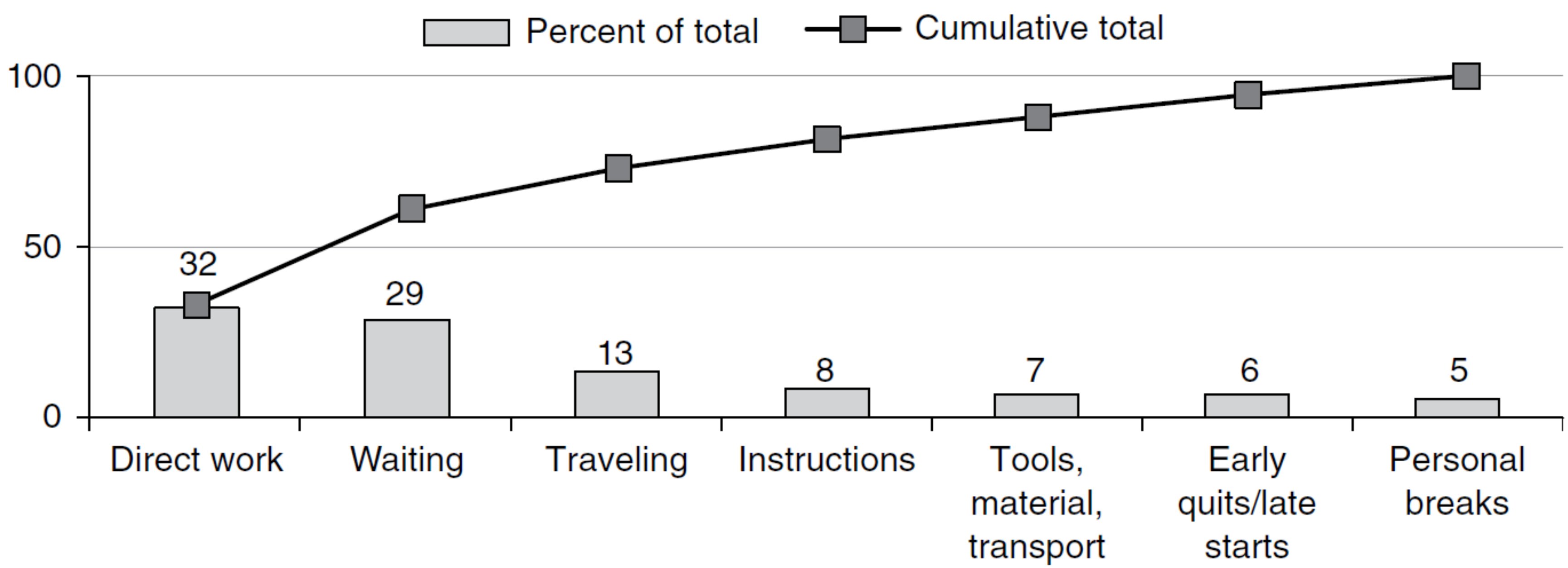
Setting up a performance measurement program

- Rework labor hours
- Schedule productivity
- Subcontractor productivity
- Where applicable: Lean indicators
  - Percentage of projects complete (PPC)
  - Project waste index (PWI)

- Labor productivity is a critical component of construction productivity. Labor costs account for approximately 40% of total costs for a broad range of projects.
- These costs may account for an even greater percentage in the case of small projects.

Setting up a performance measurement program

Typical worker's hour



Setting up a performance measurement program

- A successful program starts with the top management's vision.
- They must have a commitment to excellence, with an emphasis on a culture of continuous improvement and on management by fact.
- Productivity measurement provides the organization with the facts that it needs to make the tactical changes that are required to achieve and sustain higher levels of performance.
- Leaders must communicate to the entire organization its vision, mission, and values so that the continuous improvement philosophy can be incorporated in all activities, especially with construction projects.

Setting up a performance measurement program

- At its simplest level, a productivity measurement program may be headed by an analyst that reports to a senior management level, such as a VP.
- In turn, the VP should maintain an active productivity agenda in executive meetings to keep all decision makers aware of the trends in the organization's productivity through its respective measures.
- **Productivity measures** should be selected based on key performance indicators (KPI).
- **Critical success factors (CSF)** should be identified and these should be closely linked with the organization's KPI.

Lean construction measurement

- If the organization adopts lean construction as its protocol, performance measurement is an absolute requirement in order to determine the extent of accomplishment for a **WWP**.
- **The analyst role** may be assigned to a scheduler or other staff member who has been trained in the lean construction methodology.
- Other **traditional measurements** such as labor and crew productivity are still relevant as a means of tracking overall project performance.

Lean construction measurement

✓**Transitioning from productivity measurement to performance improvement and lean construction**

- The foregoing discussions emphasize the importance of productivity measurement as a component of the greater issue of performance improvement.
- the underlying purpose of measurement is to support initiatives to improve construction performance.
- These initiatives can include lean construction and integrated project delivery, TQM, ISO 9000, or six sigma.

Construction organizations have a particular challenge to adopt this paradigm.

Lean construction measurement

✓ **"Not everything that counts can be counted, and not everything that can be counted counts."**

- Productivity measurement is both quantitatively and qualitatively vital to the profitability of a construction company.
- Management must keep up with technological innovations worldwide and seek to adapt as well as motivate employees with improved management systems.

Lean construction measurement

- ✓ To facilitate performance measurement and improvement, constructors need to develop a culture of "building in" quality, and convey that philosophy to management and workers alike.
- ✓ They should begin to adopt Deming's fourth point "End the practice of awarding business on the basis of price tag alone."

Measuring lean construction performance

- **“you cannot improve what you cannot measure.”**
- Research studies have indicated that approximately **54%** of project commitments are completed in the typical weekly schedule, using traditional project delivery.
- Lean project delivery can raise the reliability of work plans to 85% or more.
- Work accomplishment is recorded as a graphical plot of percent plans complete (PPC);

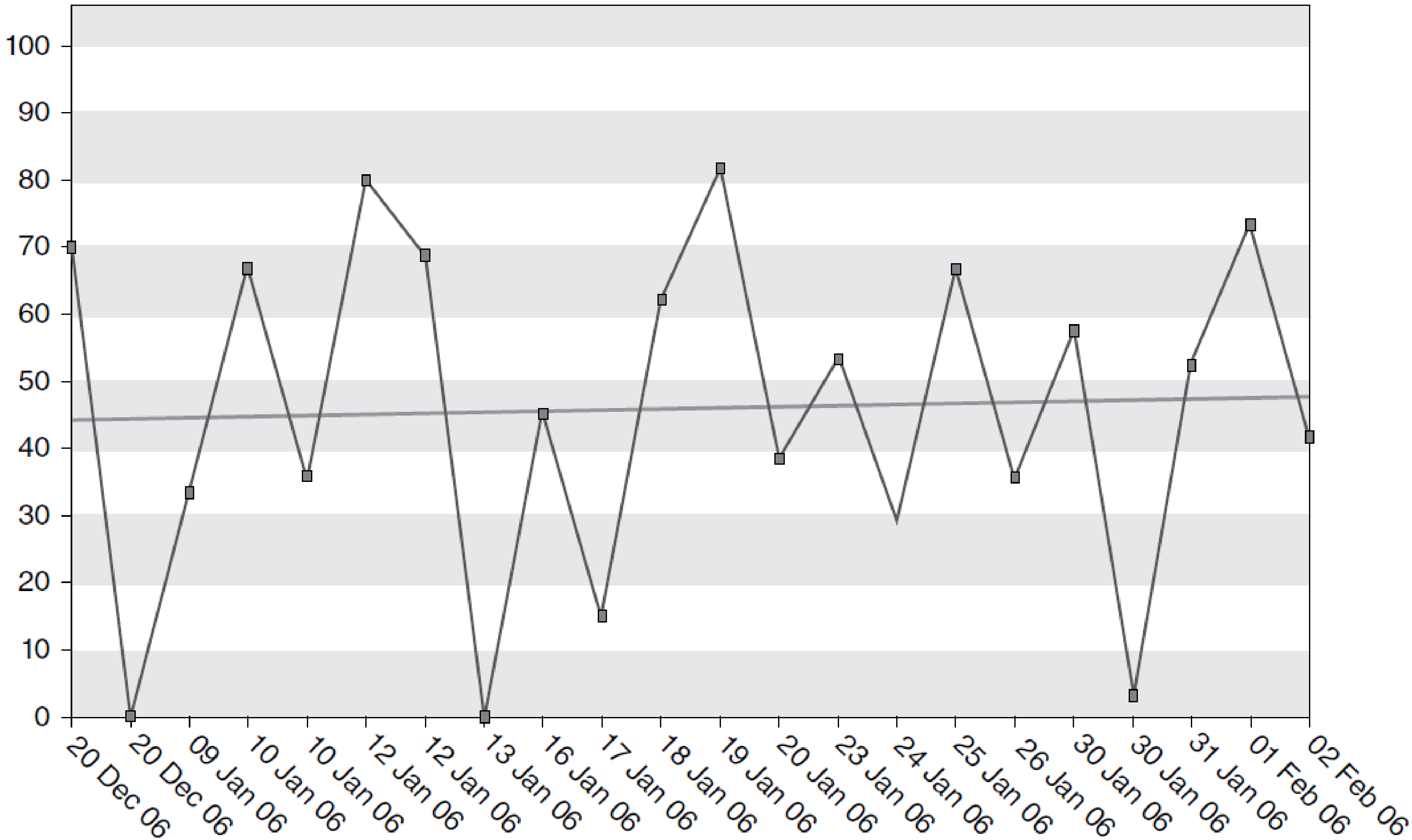
Measuring lean construction performance

In The Last Planner® System, teams commit to completing designated tasks in a given week; failure to complete all of those tasks represents less than 100% reliability.

Measuring lean construction performance

- EPC project and shows a highly fluctuating level of commitment reliability (as represented by the PPC values).
- The mean value of reliability ranges between **44 and 48%,** indicating that, on the average, fewer than half of the planned assignments are completed in a given week.
- **<u>This value is at or near zero on three occasions and between 80 and 82% on two other occasions in a 6-week period.</u>**
- In the context of lean construction, the desired outcome is to have minimal variability in the hand offs of assignments to downstream crews.

Observations on commitment reliability



Measuring lean construction performance

- In this case, the reasons for high variability were studied through a review of **reasons for noncompletion (RNC).**
- The most frequently occurring RNCs were found to be shortcomings in commitment/planning and inadequate prerequisite work.
- By addressing these issues, significant improvements were made, variability was reduced, and PPC/reliability was increased from the **45% range to over 80%**.

Learning: reasons analysis and action

- At each weekly meeting, time is devoted to learning why certain tasks were not accomplished in the previous week before creating a weekly plan for the work to be executed in the following week.
- Incomplete plans are studied to determine the root causes (reasons for non-completion) and why they were not completed in order to improve the effectiveness of future work plans.
- Pareto chart reflects the most frequently occurring reasons.
- Typically **bad planning** and **poor coordination** are frequently occurring causes.

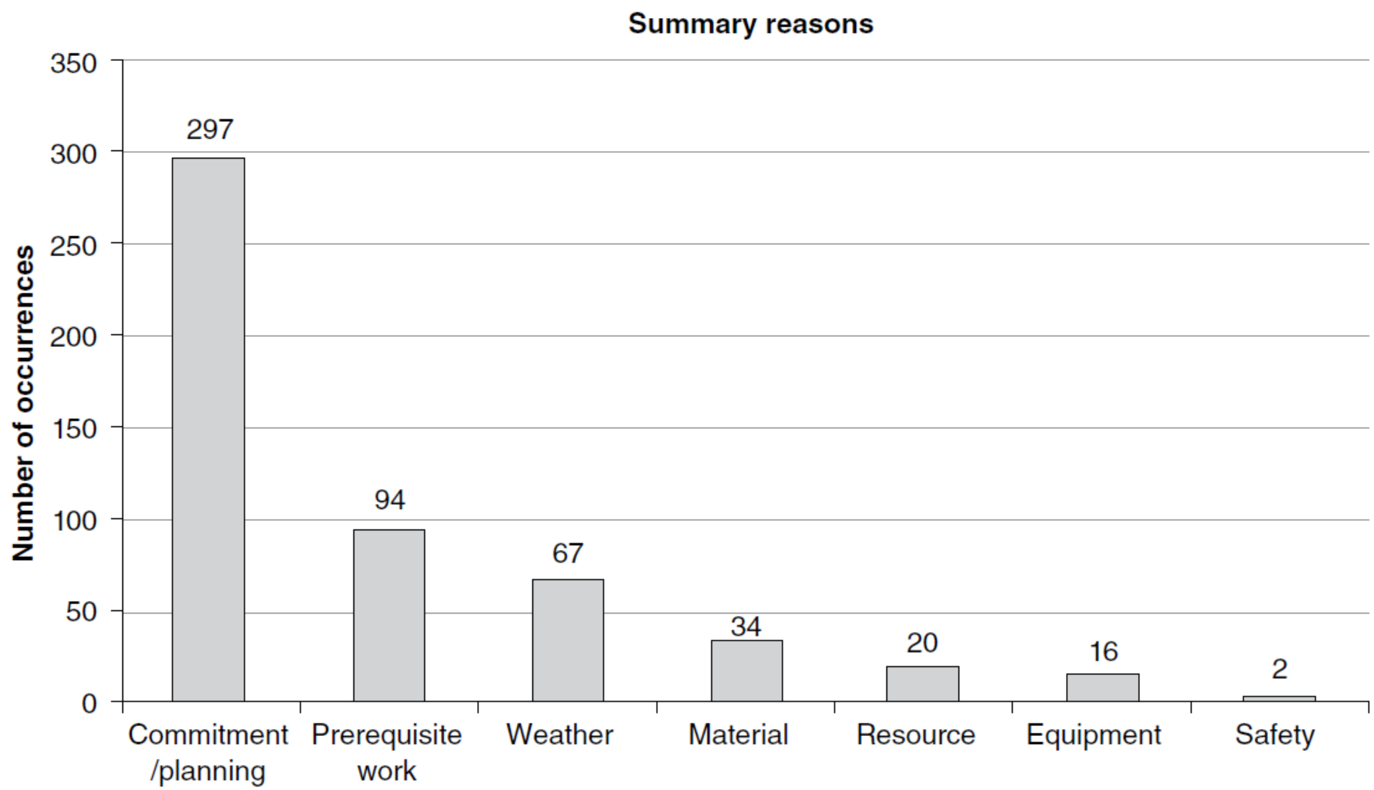
Learning: reasons analysis and action

- This exercise serves as an all-important learning tool. Without learning, crews are likely to simply repeat the mistakes of the past.

1. **Percent plan complete (PPC)** measures the degree to which work is completed as planned. It indicates the likelihood of future work accomplishment

Learning: reasons analysis and action

2. Reasons for noncompletion: These reasons are tabulated by studying incomplete plans to determine the root causes for lack of completion. These causes should be categorized in meaningful groups to facilitate identifying system-related causes.



ذکر مطالب فو

Available metrics for the Last Planner System

- Metrics are used on construction projects for monitoring and measuring the progress of work to help planners in making important decisions on time and cost improvements.

Available metrics for the Last Planner System

1. Percent Planned Complete (PPC)

Developed by Glenn Ballard (2000) the PPC value is obtained by calculating the number of complete tasks from the total tasks promised to be completed during a planning horizon, which is normally a week.

PPC = Did /Will

2. **Tasks Made Ready (TMR)**

$$\frac{\boldsymbol{Did}}{\boldsymbol{Can}}$$

3. **Tasks Anticipated (TA)**

$$\frac{\boldsymbol{Anticipated\ Tasks}}{\boldsymbol{Total\ Tasks\ on\ WWP}}$$

TMR represents the ratio of executed tasks that were made ready by removing all their constraints. TA represents the total anticipated tasks out of the total tasks found on the Weekly Work Plan (WWP) and that continued from the lookahead week.

4. **Planned Work Ready (PWR)**

$$\frac{\boldsymbol{Work\ Expected\ to\ be\ Performed\ in\ Lookahead}}{\boldsymbol{Work\ that\ Should\ be\ Performed}}$$

Available metrics for the Last Planner System

- The Planned Work Ready (PWR) metric was introduced by Mitropoulos (2005) to assess the quality of the lookahead planning process.
- PWR measures the percentage of work expected to be ready as planned in the lookahead horizon, thus acting as a forecast for the schedule performance.
- Moreover, Mitropoulos (2005) suggested three measures termed "deltas" to evaluate the make ready process:
- Delta 1 measures the constraints that are expected to be removed from the total constraints identified,
- Delta 2 measures the actual removed constraints,
- while Delta 3 looks into new identified constraints.

Available metrics for the Last Planner System

❖**Delta 1 (Δ1)**

$$\frac{Constraints\ Promised\ to\ be\ Removed}{Constraints\ Identified}$$

❖**Delta 2 (Δ2)**

$$\frac{Constraints\ Removed}{Constraints\ Promised\ to\ be\ Removed}$$

❖**Delta 3 (Δ3)**

$$\frac{New\ Constraints}{Constraints\ Identified}$$

Available metrics for the Last Planner System

❖**Percent Constraint Removal (PCR)**

$$\frac{Ready}{Can}$$

- PCR is calculated by comparing the number of ready tasks when scheduling the WWP (Ready) to the total number of planned tasks found in the lookahead plan (Can).

❖**Performance Factor (PF)**

$$\frac{Actual\ Labor\ Hours}{Earned\ Labor\ Hours}$$

Available metrics for the Last Planner System

❖**Labor Utilization Factor (LUF)**

$$\frac{EffectiveWork + \frac{1}{4}EssentialWork}{Effective + Essential + Not\ useful}$$

Available metrics for the Last Planner System

❖ **Project Productivity Index (PPI)**

$$\frac{\sum(ActivityProuctivity\ Indexes)}{N} \times 100$$

Available metrics for the Last Planner System

- Another two LPS metrics were suggested by González et al. (2008) as performance indicators at the activity level.

- The first metric above is the Project Productivity Index (PPI) calculated by finding the average of the Activity Productivity Indexes (API), with API being the ratio of the average labor productivity to the maximum labor productivity.

❖ **Planning Reliability Index (PRI)**

$$\frac{Actual\ Progress}{Planned\ Progress} \times 100$$

Available metrics for the Last Planner System

- The second metric is the Process Reliability index (PRI) concerned with the planning reliability at the activity level.

- **Construction Flow Index (CFI)**

$$10\sum_{i=1}^{7} W_i P_i^{x_i}$$

Available metrics for the Last Planner System

- Sacks et al. (2017) introduced the Construction Flow Index (CFI) which measures the quality of construction flow in repetitive construction projects.
- CFI enables project managers to improve production flow on projects by tracking and sharing this metric with trade crews.
- This value would be calculated and tracked with the help of project management software.

Available metrics for the Last Planner System

- Another attempt to align short and long-term planning was performed by Emdanat and Azambuja (2016) by introducing three metrics to complement PPC, TA, and TMR.
- The **Commitment Level (CL)** metric measures the percentage of the committed required activities (critical activities) to the total required activities in a given work plan cycle.

Available metrics for the Last Planner System

- PRCO is the percentage of required/critical activities that are completed or expected to be completed (ongoing) on or before their promised completion dates with respect to the total required activities committed to on the work plan.

❖ **Commitment Level (CL)**

$$\frac{Required\ Will}{Should}$$

❖ **Percent Required Complete and Ongoing (PRCO)**

$$\frac{Required\ Completed + \ RequiredOngoing\ onTrack}{Required\ Will}$$

Available metrics for the Last Planner System

- Finally, Rizk et al. (2017) investigated the issue of matching load to capacity and proposed several metrics in this regard:
- Capacity to Load Ratio (CLR),
- Required Capacity Ratio (RCR), and
- Required Percent Complete (RPC).

Available metrics for the Last Planner System

- The Weekly Deviation (WD) is a metric, along with the three aforementioned metrics, that helps measure the extent of deviation from the WWP.

❖ **Capacity to Load Ratio (CLR)**

$$\frac{Total\ Completed}{WWP}$$

❖ **Required Capacity Ratio (RCR)**

$$\frac{Required\ Completed}{Total\ Completed}$$

❖ **Required Percent Complete (RPC)**

$$\frac{Required\ Completed}{Total\ Required}$$

Available metrics for the Last Planner System

While these metrics equip planners with valuable input on certain aspects of planning, each metrics is solely concerned with a specific planning feature and disregards other facets.

Available metrics for the Last Planner System

This leads to a incomplete understanding of the entire project performance and the needed planning intervention actions (Emdanat and Azambuja 2016; El Samad et al. 2017).

Available metrics for the Last Planner System

Additionally, many of those metrics were either inconsistently used or required data that was too difficult and time consuming to collect.