A Case Based Reasoning Approach for Selecting Appropriate Construction Automation Method

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Abstract –

Construction automation helps to improve productivity and project performance. This study demonstrates a methodology for evaluating project performance improvement through appropriate automation of construction processes. This quantitative evaluation approach involves a compositional modeling driven case-based reasoning methodology. Potential processes for executing the activities in a project can be explored by generating combinations of process fragments compiled from cases. This approach is demonstrated through an example of RCC column construction. It is shown that a large number of processes are possible even for simple tasks and a systematic procedure for evaluation is necessary for identifying the appropriate level of automation.

Keywords-

Case Based-Reasoning; Compositional Modeling; Discrete Event Simulation; Automated Construction; Level of Automation; Therbligs; Project Performance Improvement

1 Introduction

Automated construction has been gaining attention in the recent past because of the success of robots in other fields such as manufacturing. With growing urbanization and housing deficit in many countries, automation in construction is a promising approach. In spite of the general consensus that automated construction reduces time and cost, there is not enough research in quantitative methodologies for evaluating productivity improvement through implementing appropriate automation in construction. The broad aim of this research work is to develop a systematic methodology for productivity analysis of automated construction processes. The study specifically explores the use of simulation tools to predict productivity improvement through creating multiple processes by combining process fragments from a case base.

2 Literature Review

Simulation based performance analysis of construction projects has gained renewed interest in the recent past. Literature shows the usage of simulations in a variety of projects [1-6]. Discrete event simulation tools involving time-cost studies have been utilized for construction project performance improvement [7-10]. However, there has been limited focus on quantitative evaluation of automated construction processes [11].

An important research question is: How do you identify the optimal level of automation in construction such that there is maximum improvement in project performance?

The present DES approaches are unable to perform simultaneous analysis of multiple construction process fragments which makes the task of identifying appropriate automation challenging. The representation of non-static construction processes in DES for simulating and identifying appropriate level of automation is a significant knowledge gap in literature.

This paper introduces a methodology for addressing this knowledge gap. The novelty of the present work is in resolving the challenge of representing, modeling, and simulating non-static construction processes. This addresses “the search and explore based approach” of simulating construction operations for identifying appropriate levels of automation which would lead to overall project performance improvement through time-cost optimization.

3 A Methodology for Productivity Assessment in Automated Construction

A compositional-modelling driven case-based reasoning methodology is developed for accomplishing the objectives of this study (Figure 4). It involves discrete event simulations for the calculation of the duration taken for activities to complete the construction process. The entire construction process is decomposed into a work breakdown structure with fine levels of details. The activities are refined down to the level of basic elementary tasks called therbligs [12], which are used in the study of motion economy in workplaces for the optimization of manual labor. See Table 1 for the list of therbligs.

A case library containing multiple cases of construction activities is developed through case-study observations and by analysing videos of construction activities from the world wide web. The construction activities in each case are decomposed into a hierarchical structure as shown in Figure 1. Depending upon the processes that are adopted in a case for the sub-activities, cases performing the same top-level activity might have different decompositions. An object-oriented representation is used to represent activities in which the activities are grouped into activity classes. Any two activities that belong to the same parent class can potentially be interchanged during case adaptation, provided all the constraints are met. Thus, case adaptation helps to create multiple processes for the same top-level task.

Table 1. List of therbligs

Sl. No.	Therbligs	Sl. No.	Therbligs
1	Search	10	Use
2	Find	11	Disassemble
3	Select	12	Inspect
4	Grasp	13	Preposition
5	Hold	14	Release Load
6	Transport Loaded	15	Unavoidable Delay
7	Transport Empty	16	Avoidable Delay
8	Position	17	Plan
9	Assemble	18	Rest

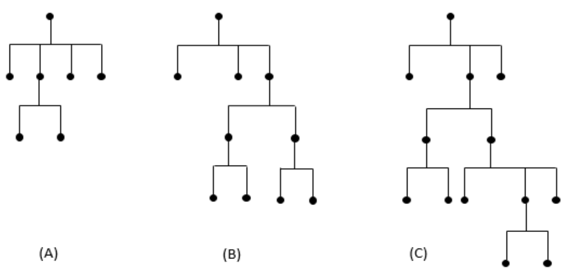


Figure 1. A schematic representation of multiple activity cases

3.1 Description of RCC Column

An example of RCC column (Figure 2) construction is taken here to illustrate the concept of model composition and performance evaluation. Many methods of column construction are automatically generated and simulated for identifying the best process meeting the requirements of time and cost.The properties are listed as follows: Dimension: 300 x 200 x 3200; Reinforcement details: 6 numbers of 14mm rods as main reinforcement; 8mm diameter shear stirrups @ 100mm c/c with 25mm cover.

The following assumptions are made: the column is at the ground level and the foundation work is completed already. The main reinforcements of the column are lapped to the foundation reinforcement. The resources are already available at site for preparation and execution.

Remark: The illustration is a part of a larger RCC-frame structure involving a combination of columns and beams, which is significantly complex, voluminous, and sophisticated. However, the authors have chosen to the present a single column based demonstration in this paper for introducing the research framework with emphasis on the fundamental concepts in it.

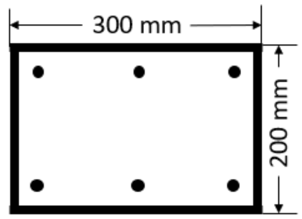


Figure 2. Cross-section of RCC column

3.2 Work breakdown structure of RCC Column

A detailed work breakdown structure of the RCC column construction is presented here for illustration. This hierarchy contains the construction of the Column unit as the top-level task (Table 2). Steel work and concreting are the main sub-activities. The steel work is further decomposed into main reinforcement and stirrup work. The main reinforcement activity is decomposed into transporting from stock to cutting yard, cutting, transporting to site location, assembling. Similarly, the stirrup activity is decomposed into transporting from stock to cutting yard, cutting, bending transporting to site location, assembling. The concreting involves shuttering, concreting, de-shuttering, and curing.

Table 2. A portion of work breakdown structure for

RCC column construction

Activity	Description
1	RCC column construction
1.1	Steel reinforcement assembly
1.1.1	(A) Fabrication
1.1.1.1	(A.1) Main reinforcement
1.1.1.1.1	(A.1.1) Transporting from Stockyard to Cutting yard
1.1.1.1.2	(A.1.2) Cutting to Measured Size
1.1.1.2	(A.2) Stirrup
1.1.1.2.1	(A.2.1) Transporting from Stockyard to Cutting yard
1.1.1.2.2	(A.2.2) Cutting to Measured Size
1.1.1.2.3	(A.2.3) Bending to Shape

3.3 Case-library of construction processes

A case-library of construction processes has been compiled from on-site observations and videos of construction activities. The cases contain multiple possibilities of activity execution modes based on the work breakdown structure of the activities used for the construction. For every activity, cases of either manual, mechanical, or electromechanical options are considered. The therbligs based data for the case library is acquired by analysing world-wide-web based video resources.

4 Performance evaluation of processes

For a new project, multiple processes are generated by adapting similar cases. The primary method of adaptation is substitution of similar activities based on their inheritance relationship. The generated processes are simulated using a discrete event simulation software. Implementation details of modeling and simulation are provided below.

4.1 Model generation

Cases are represented in XML format. Cases contain the decomposition of the process as well as the resources utilized for the activities. The activities are decomposed in to therbligs with corresponding durations (Figure 3). Data required for executing simulations are also included in the case files.

All activities are classified using inheritance relationships. The activities can be run in sequence or parallel based on the case considered. The number of cycles of therbligs are also specified. A sample XML file is shown in Figure 5.

4.2 Generating solutions for a new problem

The data related to the new project is provided as input to the CBR module. Multiple processes are generated by case adaptation. Each adapted case combines parts of activities of the previous cases and generates a new process solution. This approach of combinatorial model generation leads to development of new processes that includes combinations of activities from across the case library.

An in-house developed simulation tool, AutoDES, is utilized for performing discrete event simulations of generated processes. The simulations provide the time durations for each activity of the process (Figure 6). The cost of resources and capital costs are computed separately for each process solution.

5 Results

Simulations using compositional modeling driven case-based reasoning methodology were able to identify best processes for RCC column construction considering time and budget. The procedure involved search and exploration of activities and resources from the case library. The simulation approach offers the possibility of generating millions of combinations of activities to identify the optimal process.

For example, transporting main reinforcement from stockyard to cutting yard was most efficient with *Case 1: using a Bar Spider lifting equipment with automatic release system* (29 sec), whereas *Case-1: using a Mobile-Crane and 4 labors was least efficient* (89 sec). The cutting of main reinforcement to measured size with *Case 5: Cutting rebar with a Circular Saw* took 16sec, while *Case 4: Cutting rebar with a handheld hydraulic rebar cutter* took 30sec. Rebar bending with *Case 2: Mechanical bending of rebar to shape with a bar-bender* took 84sec, whereas Cases 4 and 5: *Automated bending of rebar to shape with a bar-bender: Type-1* and *2* took only 44sec.

Considering the combinatorial possibilities, least time consuming RCC column construction process took 1342 sec, the most time consuming process took 4125 sec, and the optimal time consuming process took 2116 sec. (It should be noted that activities related to formwork, curing, etc. have not been included in this model, to keep the example simple enough). All the three solutions are a combination of manual, mechanical, electromechanical device based activities. It was possible to identify the level of automation for each of the solution cases through this methodology.

6 Summary and Conclusion

This paper introduced a compositional modeling driven case-based reasoning methodology for improving project performance through optimal level of automation in construction process. For illustration, a typical RCC construction task was considered. In order to explore various methods of construction with different levels of automation, a case library was used. Each case consists of a method of construction using different tools and techniques. Representing a case involves breaking the construction process in to activity fragments up to the basic level of elementary tasks called therbligs. These activities can be performed through multiple approaches involving manual, mechanical, electro-mechanical or any other means.

The study demonstrates that a large number of processes are possible even for simple tasks in construction and a systematic methodology is needed for identifying the best process involving appropriate level of automation. Results indicate possibility of significant savings in construction time through automation implementation. Moreover, present study showcases a process simulation tool that can be utilized for the evaluation of the overall construction process of a project.

Further work is in progress involving refining and testing of the methodology through much more complex combination of activity cases. Future research would lead to a greater and deeper understanding on implementation of optimal level of automation in construction process. This would possibly prove positive impact of automation on the overall project performance.

7 Acknowledgements

The authors wish to thank Mr. Saqib Bhat and Mr. Utkarsh Kumar who helped in this study during data segregation and pre-processing while generating the construction process case library.

This project is funded by the Department of Science and Technology (DST) and Science and Engineering Research Board (SERB), India, through the grants DST/TSG/AMT/2015/234 and IMP/2018/000224.

```
<therblig_Search>
  <Object> rebar </Object>
  <Source> rebarStack </Source>
  <Duration> 0,1 </Duration>
</therblig_Search>

<therblig_Find>
  <Duration> 0,1 </Duration>
</therblig_Find>

<therblig_Select>
  <Duration> 0,1 </Duration>
</therblig_Select>

<therblig_Grasp>
   <Duration> 0,1 </Duration>
</therblig_Grasp>

<therblig_Hold>
  <Duration> 0,1 </Duration>
</therblig_Hold>

<therblig_Transport_Loaded>
  <Duration> 0,2 </Duration>
</therblig_Transport_Loaded>

<therblig_Preposition>
  <Duration> 0,1 </Duration>
</therblig_Preposition>
```

Figure 3. A schematic of therbligs based coding for rebar cutting activity

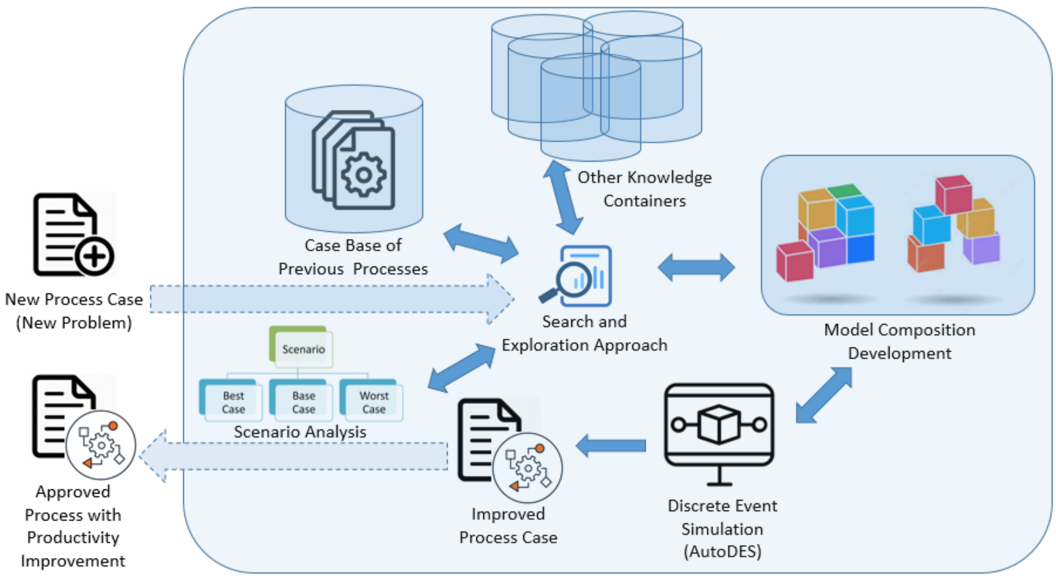
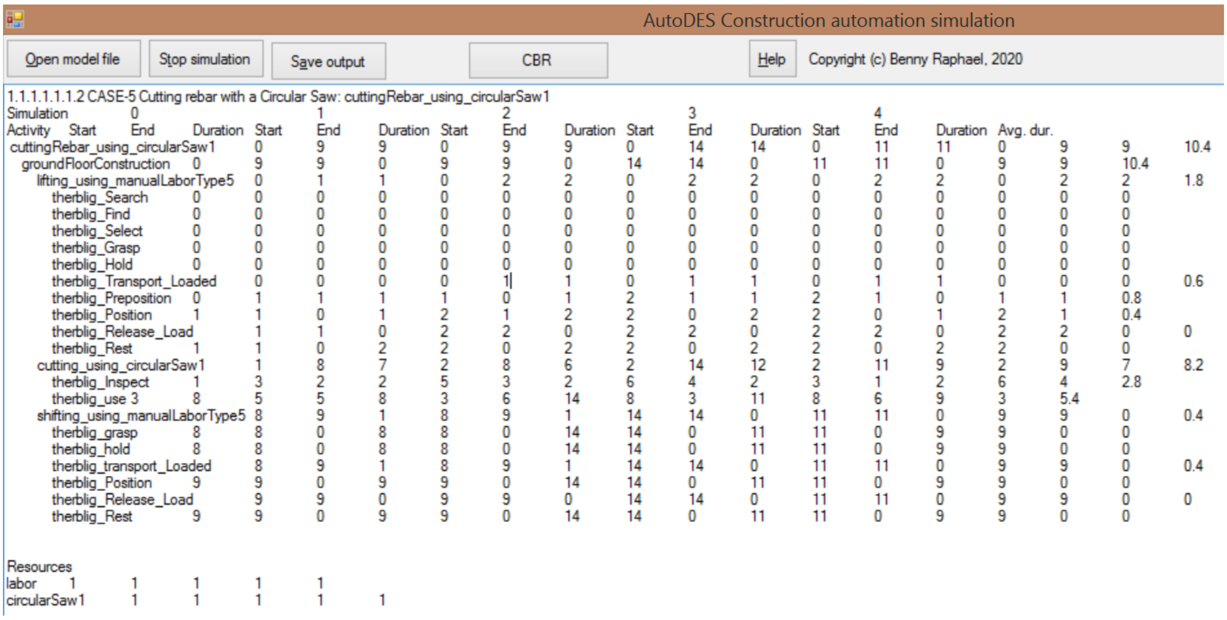


Figure 4. Compositional modelling driven case-based reasoning methodology of DES for Construction Process

.1.1.1.1.2 CASE-...eld plier type-1.xml

```xml
<?xml version="1.0" encoding="utf-8"?>
<DES>

  <Simulations> 5 </Simulations>
  <!--- Number of simulations  -->

  <Maxtime> 1000 </Maxtime>
  <!-- Maximum time steps to terminate -->

    <Resource>
    <!--- Available resources for this process -->
      <labor> 1 </labor>
      <helper> 1 </helper>
      <handHeldPlier1> 1 </handHeldPlier1>
    </Resource>

    <Model>
      <Description> cuttingRebar_using_manualLaborWithPlierType1 </Description>
      <!-- This is the description of a specific "process case" in this model. -->
      <!-- 1.1.1.1.1.1.2 CASE-1 Manually cutting rebar with hand-held plier type-1 (as mentioned in Excel sheet) -->
      <!-- therbligs: Search  Find  Select  Grasp Hold Transport_Loaded Preposition Position Release_Load Transport_Empty
        <Activities>
          <groundFloorConstruction>
          <!-- ground floor construction, floor level of construction -->

            <Activities>

              <lifting_using_manualLaborType1>...</lifting_using_manualLaborType1>

              <cutting_using_manualLaborWithPlierType1>...</cutting_using_manualLaborWithPlierType1>

              <shifting_using_manualLaborType1>...</shifting_using_manualLaborType1>

            </Activities>
          </groundFloorConstruction>
        </Activities>
    </Model>
    <Relationships>

      <Inheritance>
        groundFloorConstruction, floorLevelofBldg
        <!-- ground floor construction, floor level of construction -->
      </Inheritance>

      <Inheritance>
        lifting_using_manualLaborType1, liftingRebar_fromUncutRebarStack_toCuttingPlatform
        <!-- lifting using Manual Labor type 01, lifting rebar from Uncut Rebar Stack to Cutting Platform -->
      </Inheritance>

      <Inheritance>
        cutting_using_manualLaborWithPlierType1, cuttingRebar_atCuttingPlatform
        <!-- cutting using Manual Labor with plier type 01, cutting Rebar at Cutting Platform -->
      </Inheritance>

      <Inheritance>
        shifting_using_manualLaborType1, shiftingRebar_fromCuttingPlatform_toCutStack
        <!-- shifting using Manual Labor type 01, shifting Rebar from Cutting Platform to Cut Stack -->
      </Inheritance>

    </Relationships>
```

Figure 5. A sample XML file showing the inheritance relationships between classes



AutoDES Construction automation simulation

Open model file | Stop simulation | Save output | CBR | Help | Copyright (c) Benny Raphael, 2020

1.1.1.1.1.1.2 CASE-5 Cutting rebar with a Circular Saw: cuttingRebar_using_circularSaw1

Simulation	0			1			2			3			4			
Activity	Start	End	Duration	Start	End	Duration	Start	End	Duration	Start	End	Duration	Start	End	Duration	Avg. dur.
cuttingRebar_using_circularSaw1	0	9	9	0	9	9	0	14	14	0	11	11	0	9	9	10.4
groundFloorConstruction	0	9	9	0	9	9	0	14	14	0	11	11	0	9	9	10.4
lifting_using_manualLaborType5	0	1	1	0	2	2	0	2	2	0	2	2	0	2	2	1.8
therblig_Search	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
therblig_Find	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
therblig_Select	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
therblig_Grasp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
therblig_Hold	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
therblig_Transport_Loaded	0	0	0	0	1	1	0	1	1	0	1	1	0	0	0	0.6
therblig_Preposition	0	1	1	1	1	0	1	2	1	1	2	1	0	1	1	0.8
therblig_Position	1	1	0	1	2	1	2	2	0	2	2	0	1	2	1	0.4
therblig_Release_Load	1	1	0	2	2	0	2	2	0	2	2	0	2	2	0	0
therblig_Rest	1	1	0	2	2	0	2	2	0	2	2	0	2	2	0	0
cutting_using_circularSaw1	1	8	7	2	8	6	2	14	12	2	11	9	2	9	7	8.2
therblig_Inspect	1	3	2	2	5	3	2	6	4	2	3	1	2	6	4	2.8
therblig_use 3	8	5	5	8	3	6	14	8	3	11	8	6	9	3	5.4	
shifting_using_manualLaborType5	8	9	1	8	9	1	14	14	0	11	11	0	9	9	0	0.4
therblig_grasp	8	8	0	8	8	0	14	14	0	11	11	0	9	9	0	0
therblig_hold	8	8	0	8	8	0	14	14	0	11	11	0	9	9	0	0
therblig_transport_Loaded	8	9	1	8	9	1	14	14	0	11	11	0	9	9	0	0.4
therblig_Position	9	9	0	9	9	0	14	14	0	11	11	0	9	9	0	0
therblig_Release_Load	9	9	0	9	9	0	14	14	0	11	11	0	9	9	0	0
therblig_Rest	9	9	0	9	9	0	14	14	0	11	11	0	9	9	0	0

Resources					
labor	1	1	1	1	1
circularSaw1	1	1	1	1	1

Figure 6. Simulation result of Case-5: Cutting rebar with a circular saw Improvement

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