USING B.I.M. IN DESIGNSTAGE OF CONSTRUCTION PROJECTS TO MINIMISE HEALTH AND SAFETY RISKS: PROPOSING A MODEL FOR APPLICATION OF B.I.M. IN P.T.D.

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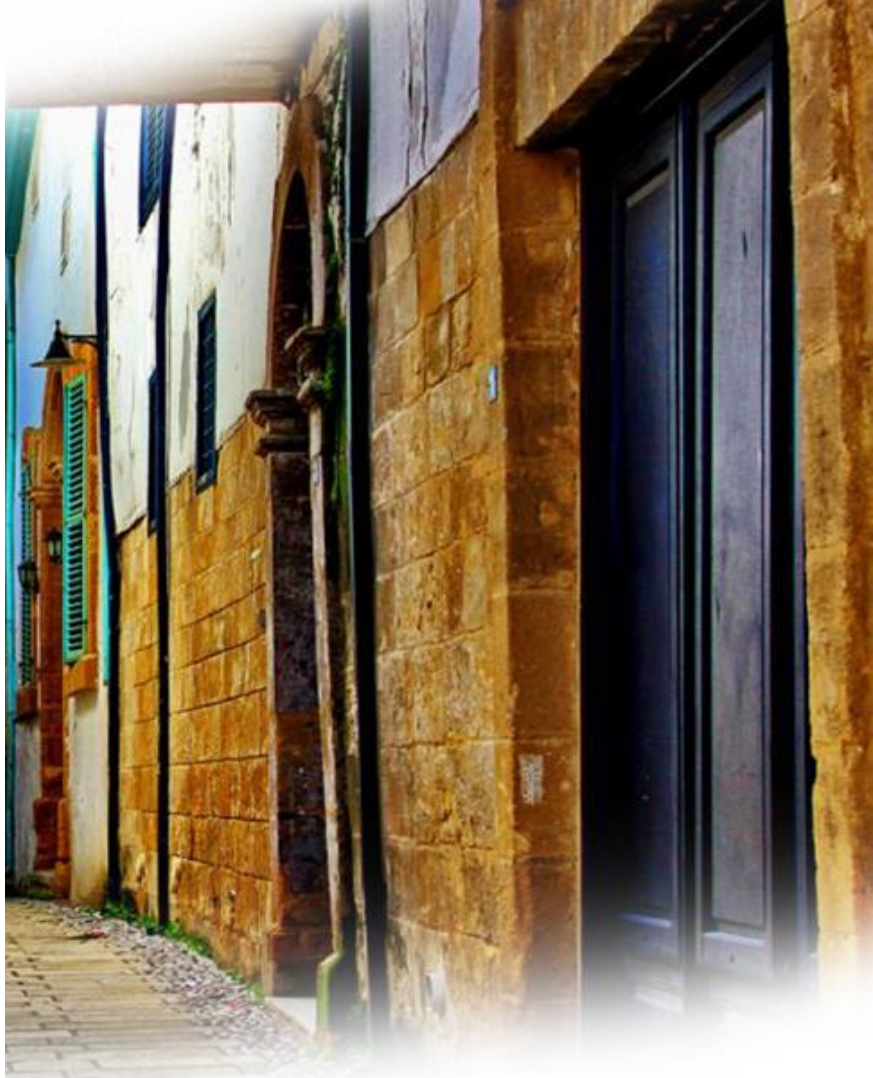

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INTRODUCTION

- **Construction** industry is **one of the largest industry** globally in **providing employment** capacity, **production**, and **contributing to the economy** (International Labour Organization).
- At the same time, **occupational accidents** take place **the most frequently**, in **construction industry**, almost **every country**.
- Around **30%** of fatal occupational **accidents** worldwide, take place in **construction Works.**

WHY?

- **Construction industry** is a **project based** industry, **different job activities** exist, each activity **creates different risks** and **each project** has its **own characteristics** as well as **risks**.

- Moreover, **coordination** of **subcontractors** as well as **main contractors** is **very difficult** (IOSH, 2018).
- It can be seen that the **probability** of **fatal accidents** of **construction** workers is **3-4 times higher** than **other industries** in many countries (HSE,2018).
- As a result of this dynamic structure of the sector, individuals working at construction industry having accidents very frequently.

- **The disturbing part of this situation is that, the majority of hazards on the construction site emerge due to the decisions during design phase. And unfortunately, thay are not realized until the execution of the construction.**

However, **Prevention Through Design (PtD)** approach **argues** that, **OHS** should be **considered in the beginning of project design**.

Accordingly it is **possible** to **determine** and **minimise** the **hazards imediatly**, which can emerge with the decisions **at the design phase**, with **small changes** and **without damaging** the **character, function, aesthetic** of the **structure**.

Is it possible to minimise the construction accidents related with design decisions during briefing and design stage of construction projects?

OBJECTIVES

- To **organize** and **computerize** all occupational **accidents** in TRNC since 1994 to 2014.
- **Classify** the **accidents** in **construction industry** and **define** the **most critical** type of accidents in TRNC.
- **Identify** the **relationship** between the most critical **accidents** and **design decisions.**
- Define the **activities** and **sub-activities** performed during the construction of mentioned design decisions which creates occupational risks.
- Perform a **risk analysis** for activities and sub-activities to **define** the **level** of **risks**.
- **Proposing design alternatives** named as secondary design **to minimize occupational** risks for above mentioned critical activities and sub-activities.

and,

Developing a system named as Hazard Identificatiın System (HIS) that works in a BIM software (REVIT) to define riskfull design decision, propose alternative designs to minimize occupational risks and accidents.

RESEARCH METHODOLOGY

In the **first phase** of study, the **design decisions** that the **thesis would focus** on are **determined**.

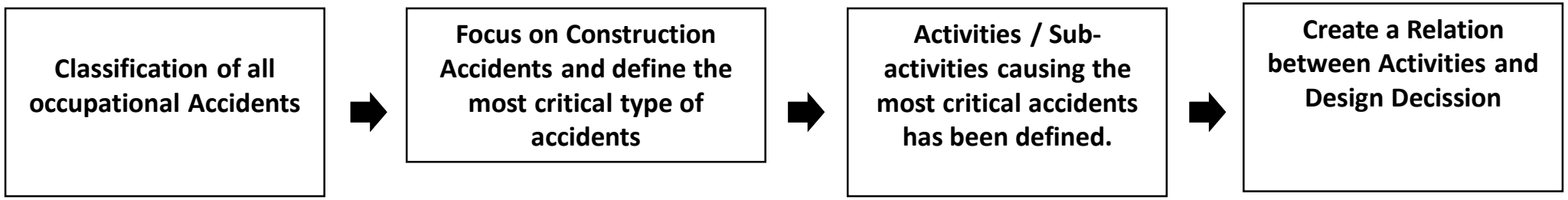
For doing this, the **following steps are performed**:

- The **occupational accidents** happened in the TRNC were **classified.**
- The **most common** type of **construction accidents** were **identified**.
- The **main activities** (work items) that **accidents occur during execution** were **defined.**
- Than, this **activities associated** with **Design Decissions**.

For Example:

Activity is “exterior walls plastering works”.

Design decision is “building the exterior walls with bricks/block materials”.



In the **second phase** of the study;

- **Fine-Kinney method** has been **used** to do the **risk assessment**

- And the **risk scores** for **Design Decission** were **calculated.**

Design Decission			
Activity 1		**Activity 2**	
Sub-Activity 1.1	**Sub-Activity 1.2**	**Sub-Activity 2.1**	**Sub-Activity 2.2**
Risk Score (SA1.1)	**Risk Score (SA1.2)**	**Risk Score (SA2.1)**	**Risk Score (SA2.2)**
SA1.1 + SA1.2 + SA2.1 + SA2.2 = Risk Score of Design Decission			

In the **third phase** of the study;

- the **(alternative)** secondary **design decisions** were **proposed** and all of the **same procedures** (Risk Analysis Procedure) **applied** on the **alternative** (secondary) **design decisions**.

Afterwards;

- the **risk scores** of **primary and secondary design decisions** were **compared.**
- Then, outcomes **converted into** an software package **(**named as **HIS)** on **REVIT** by the help of **DYNAMO.**

WORK DONE

Firstly, defined the,

- **Industrial Distribution of Accident Records in TRNC**

Industry	Fatality	Injury	Total	(%)	Fatality Rate Within the Industry (%)
Construction	42	751	793	26.40	5.30
Carpentry	1	190	191	6.36	0.52
Industry	7	437	444	14.78	1.58
Service	7	350	357	11.88	1.96
Business	5	238	243	8.09	2.06
Costal & harbor Works	5	117	122	4.06	4.10
Logistics	2	84	86	2.86	2.33
Quarries	5	41	46	1.53	10.87
Other	12	710	722	24.03	1.66
Total	86	2918	3004	100.00	2.86

Other: agriculture, horticulture, banking, education, public and private industry office work

After that,

- **Identification of the Most Common Construction Accident Types**

Causes of Accidents	ICD-10 Codes	Fatality		Injury		Total	
		No.	%	No.	%	No.	%
Building & Construction Collapse	W20	2	4.76	4	0.5	6	0.757
Cave-in	W20	1	2.38	5	0.7	6	0.757
Contact with Chemical Substances	T52-T59		0	4	0.5	4	0.504
Contact with heat or hot substances	X10-X19		0	23	3.2	23	2.9
Crashed, Jammed in or Between Objects	W23	3	7.15	84	11	87	10.97
Explosives	W36-W40		0	6	0.9	6	0.757
Exposure to Electric	W85, W86	10	23.8	9	1.3	19	2.396
Fall on Same Level	W1, W3, W10		0	62	8.3	62	7.818
Falling Objects	W20	2	4.76	57	7.7	59	7.44
Falls	**W12, W13**	**21**	**50**	**278**	**37**	**299**	**37.7**
Sharp Object İnjury	W25-W29		0	63	8.5	63	7.945
Striking against or struck by objects	W22		0	8	1.1	8	1.009
Struck by thrown, projected object	W20		0	86	11	86	10.84
Traffic Accident	V00-V60	3	7.15	54	7.2	57	7.188
unknown			0	8	1.1	8	1.009
Total		**42**	**100**	**751**	**100**	**793**	**100**

Than focus on falls and

- **Detailed Classification of Falls**

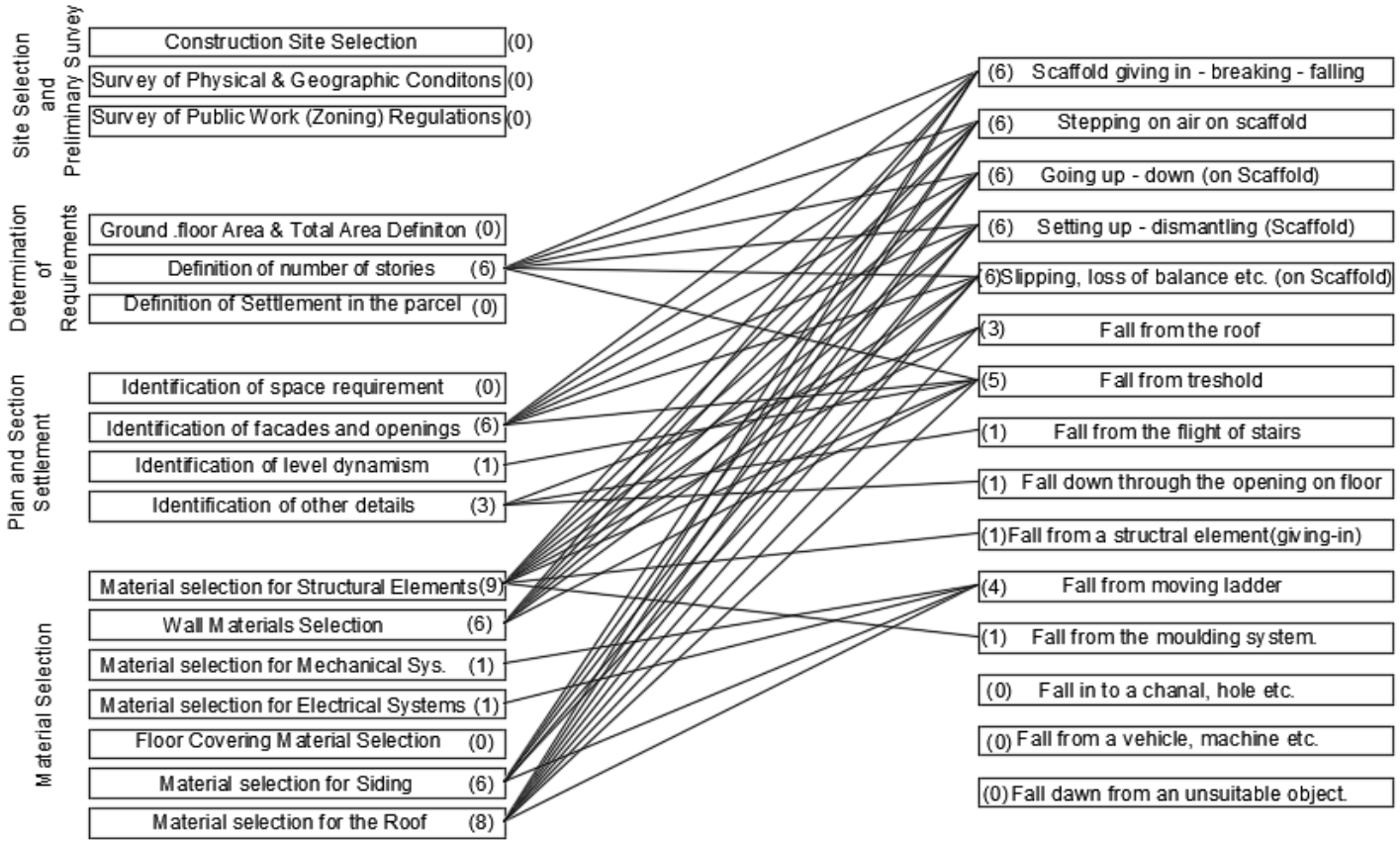
Falls from scaffolds			
Type of Falls (W12, W13)	**Fatality**	**Injury**	**Total**
Scaffold giving in-breaking-falling	3	24	27
On the scaffold (stepping on air)	1	9	10
On the scaffold (while going up-down)	0	7	7
On the scaffold (setting up-dismantling)	0	5	5
On the scaffold (slipping, loss of balance etc.)	1	36	37
Sub. Total	5	81	86

Falls from structural elements			
Type of Falls (W12, W13)	**Fatality**	**Injury**	**Total**
Falls from structural element (from the roof)	0	10	10
Falls from structural element (from threshold(edge))	3	28	31
Falls from structural element (flight of stairs)	1	6	7
Falls from structural element giving in (Collapse)	1	1	2
Falling down through opening on the floor	2	7	9
Sub. Total	7	52	59

Other type of falls			
Type of Falls (W12, W13)	**Fatality**	**Injury**	**Total**
Moving ladder	4	54	58
From the molding system	2	18	20
Into a canal, hole etc.	0	13	13
From a vehicle, machine	2	35	37
Going up on unsuitable object	1	14	15
Other	0	11	11
Sub. Total	9	145	154
Total	**21**	**278**	**299**

Decided to

- **Associate the Fall From Height Type of Accidents with Design Decission**



As a result, following design decissions are associated with fall type of accidents.

1. Definition of Number of stories

2. Identification of Facades

3. Material selection of Structral Elements

4. Wall Material selection

5. Material Selection of Siding

6. Material selection of the roof Parapets

7. Material selection of mech and Electrical Systems

Than,

Association of the selected Primary Design Decissions with

- **Activities,**
- **Sub-Activities**
- **Work Environment**

have been established.

After that,

- **Risk Analysis of Primary (Initial) Design Decissions**

have been compleated.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Initial Design Decision	Activity	Sub – Activity	Work Place	Definition of Risk	Likelihood	Exposure	Impact	R.Score	Decission	Act	Design D. R.S.
Design of exterior walls with bricks, blocks etc. (1)	Exterior Wall Works	Carrying brick, blocks	Scaffold	Falling Down To The Ground Upon Losing Balance While Working On Scaffold	10	10	40	4000	Very High Risk	Stop the Works Immediately and Measures To Be Taken	**21620** (Design of exterior walls with bricks, blocks etc.)
		Carrying mortar-Giving mortar									
		Walling									
	Exterior Plastering	Carrying plaster materials etc.									
		Plastering		Falling Due To “Step in to Air” While Working On Scaffold	10	10	40	4000	Very High Risk	Stop the Works Immediately and Measures To Be Taken	
	Exterior Paint and Maintenance	Repair of façade cracks etc.									
		Preparation of painting area, sandpapering									
		Carrying paint, repair materials etc.		Falling Due To Breakage Of Scaffold Element	6	6	40	1440	Very High Risk	Stop the Works Immediately and Measures To Be Taken	
		Painting façade									
		Post-paint cleaning works									
	Exterior Coating Works and Maintenance	Carrying and cutting support profiles of system		Falling Due to the Rollover of Unfixed Scaffold System	10	6	100	6000	Very High Risk	Stop the Works Immediately and Measures To Be Taken	
		Installation and welding works of support profiles									
		Carrying coating materials									
		Installation of coating materials									
		Availability of insulation etc. details on connection points and whole façade		Falling Due to The Heavy Weight of Object in Hand	6	6	40	1440	Very High Risk	Stop the Works Immediately and Measures To Be Taken	
	Exterior Insulation Works and Maintenance	Repair of cracks on façade etc.									
		Elimination of burrs on the surfaces where insulation would be applied									
		Carrying insulation repair material and insulation material		Dropping Materials Due to Various Reasons While Working On Scaffold	10	10	15	1500	Very High Risk	Stop the Works Immediately and Measures To Be Taken	
		Application of insulation material on façade									
		Application of protective surfacing and preparation of façade for paint									
	Exterior Wall Works	Carrying brick, blocks	Flooring edge (threshold)	Falling Down To The Ground Upon Losing Balance On the Flooring Edge	6	6	40	1440	Very High Risk	Stop the Works Immediately and Measures To Be Taken	
		Carrying mortar-Giving mortar		Falling Due To “Air-Step” On The Flooring Edge	6	6	40	1440	Very High Risk	Stop the Works Immediately and Measures To Be Taken	
		Walling		Falling Due To Breakage Of Protective Barriers on Threshold	3	3	40	360	High Risk Risk	Short Term Action Plan For Remedy	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Initial Design Decision	Activity	Sub – Activity	Work Place	Definition of Risk	Likelihood	Exposure	Impact	R.Score	Decission	Act	Design D. R.S.
No central system for air conditioning/ ventilation system etc. (2)	Exterior Installation and Maintenance of Air Conditioning / Ventilation System	Preparation of air conditioning infrastructure	Flooring edge (threshold)	Falling Due To Complete or Partial Collapse of Flooring	1	1	100	100	Significant Risk	Monitoring and Including under Annual Action Plan	**<u>1360</u>** (No central system for air conditioning/ ventilation system etc.)
		Carrying infrastructure material, air-conditioner etc.		Falling Due to The Heavy Weight of Object in Hand on the Threshold	3	6	40	720	Very High Risk	To Halt the Works Immediately and Measures To Be Taken	
	Exterior Installation and Maintenance of Air Conditioning / Ventilation System	Installation of external unit of air conditioner		Dropping Materials While Working on Threshold	6	6	15	540	Very High Risk	To Halt the Works Immediately and Measures To Be Taken	
		Preparation of air conditioning infrastructure	scaffolding	No need to work on scaffolding or on the edge of slabs.	0	0	0	0	No Risk	No Act.	
		Installation of external unit of air conditioner									
Incorrect design of barrier, parapet etc. that would prevent falls from the roof, or no design at all (3)	Roof Insulation Works and Maintenance	Setting up the roof or preparation of existing roof surface for application	Roof edge (threshold)	Falling Down To The Ground Upon Losing Balance On the Roof Edge	6	6	40	1440	Very High Risk	To Halt the Works Immediately and Measures To Be Taken	**<u>4600</u>** (Incorrect design of barrier, parapet etc. that would prevent falls from the roof, or no design at all)
		Carrying roof insulation material		Falling Due To “Air-Step” On The Roof Edge	6	6	40	1440	Very High Risk	To Halt the Works Immediately and Measures To Be Taken	
		Application of insulation material on the roof		Falling Due To The Breakage of Protective Barriers	3	3	40	360	High Risk	Short Term Action Plan For Remedy	
		Placement of protective roof cover		Falling Due To Complete or Partial Collapse of Roof	1	1	100	100	Significant Risk	Monitoring and Including under Annual Action Plan	
	Installation and Maintenance of other Mechanic or Electronic System on the Roof	Carrying mechanic, electronic system materials and infrastructure materials		Falling Due to The Heavy Weight of Object in Hand on the Threshold	3	6	40	720	Very High Risk	To Halt the Works Immediately and Measures To Be Taken	
		Preparation of infrastructure		Dropping Materials While Working on Threshold	6	6	15	540	Very High Risk	To Halt the Works Immediately and Measures To Be Taken	
		Installation and assembly of system elements									

Risk scores of selected design decissions **found very high.**

Thats why **alternative design decission** have been **defined** for decresing the risk score

Design Decission 1: **Wall Material selection**	
Primary Design Decission (Common in TRNC)	**Secondary (Alt.) Design Decission**
Design of exterior walls with bricks, blocks	Exterior pre-cast Pannel walls
Design Decission 2: **Material selection of mech & Electrical Systems**	
Primary Design Decission(Common in TRNC)	**Secondary (Alt.) Design Decission**
Non-central system for air conditioning/ ventilation system	Central system for air conditioning/ ventilation system
Design Decission 3: **Material selection for the roof**	
Primary Design Decission(Common in TRNC)	**Secondary (Alt.) Design Decission**
Incorrect design of parapets for the roof	Correct Design of parapet

After that,

Association of Secondary (Alternative) Design Decission have been established with,

- **Activities,**
- **Sub-Activities**
- **Work Environment**

And,

- **Risk Analysis of Secondary (Alternative) Design Decissions**

have been compleated.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Design Decision	Activity	Sub - Activity	Work Place	Definition of Risk	Likelihood	Exposure	Impact	R. Score	Decission	Act	Design D. R.S.
Exterior pre-cast Pannel wall system	Exterior Wall Works	Bringing precast panels to the construction site	Outside Building (Around)	Construction Site Vehicle Machinery Accident	1	0.5	15	7.5	Acceptable Risk	Urgent Measure May Not Be Needed	**2763.1** (Exterior pre-cast pannel wall system)
				Jammed To The Gap While Unloading	3	1	15	45	Definite Risk	To Be Included Under Action Plan	
		Unloading and piling precast panels to the construction site		Hit by the object falling from the crane due to rope breakage	0.5	0.5	40	10	Acceptable Risk	Urgent Measure May Not Be Needed	
				Hit by the surrounding objects etc. due to the movement of load on the crane	1	1	40	40	Definite Risk	To Be Included Under Action Plan	
		Lifting and Placing precast panels with a crane		Rollover of crane	0.2	0.2	100	4	Acceptable Risk	Urgent Measure May Not Be Needed	
				Fall of load on the crane as a result of release	0.5	1	40	20	Acceptable Risk	Urgent Measure May Not Be Needed	
		Fixing the panels placed with the crane	Flooring Edge (Threshold)	Falling Down To The Ground Upon Losing Balance On the Flooring Edge	3	3	40	360	High Risk	To Be Eliminated Through Short-term Action Plan	
				Falling Due To “Air-Step” On The Flooring Edge	3	3	40	360	High Risk	To Be Eliminated Through Short-term Action Plan	
				Falling Due To Breakage Of Protective Barriers on Threshold	0.5	1	40	20	Acceptable Risk	Urgent Measure May Not Be Needed	
		Finishing and Making the fixed panel ready to use		Falling Due To Complete or Partial Collapse of Flooring	0.2	0.2	40	1.6	Acceptable Risk	Urgent Measure May Not Be Needed	
				Falling Due to The Heavy Weight of Object in Hand on the Threshold	3	1	40	120	Significant Risk	Closely Monitored, To Be Taken Under Annual Action Plan	
				Dropping Materials While Working on Threshold	3	1	15	45	Definite Risk	To Be Taken Under Action Plan	
	Exterior Paint and Maintenance	Repair of façade cracks etc.	Scaffold	Falling Down To The Ground Upon Losing Balance While Working On Scaffold	10	1	40	400	High Risk	To Be Eliminated Through Short-term Action Plan	
		Preparation of painting area, sandpapering		Falling Due To “Air-Step” While Working On Scaffold	10	1	40	400	High Risk	To Be Eliminated Through Short-term Action Plan	
		Carrying paint, repair materials etc.		Falling Due To Breakage Of Scaffold Element	6	1	40	240	High Risk	To Be Eliminated Through Short-term Action Plan	
		Painting façade									
		Post-paint cleaning works		Falling Due to the Rollover of Unfixed Scaffold System	6	0.5	100	300	High Risk	To Be Eliminated Through Short-term Action Plan	
	Exterior Coating Works and Maintenance	Carrying and cutting support profiles of system		Falling Due to The Heavy Weight of Object in Hand	6	1	40	240	High Risk	To Be Eliminated Through Short-term Action Plan	
		Installation and welding works of support profiles									
		Carrying coating materials		Dropping Materials Due to Various Reasons While Working On Scaffold	10	1	15	150	Significant Risk	Closely Monitored, To Be Taken Under Annual Action Plan	
		Installation of coating materials									

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Design Decision	Activity	Sub - Activity	Work Place	Definition of Risk	Likelihood	Exposure	Impact	R. Score	Decission	Act	Design D. R.S.
Central system for air conditioning/ ventilation system etc.	Installation and Maintenance of Air Conditioning / Ventilation System	Preparation of air conditioning infrastructure Carrying infrastructure material, air-conditioner etc. Installation of external unit of air conditioner Preparation of air conditioning infrastructure Installation of external unit of air conditioner	In-building Work	No fall from height risk detected for central system	-	-	-	-	-	-	0 (Central system for air conditioning/ ventilation system etc.)
Design of barrier, parapet etc. that would prevent falls from the roof	Roof Insulation Works and Maintenance	Setting up the roof or preparation of existing roof surface for application	Roof Edge (Threshold)	Falling Down To The Ground Upon Losing Balance On the Roof Edge	0.2	0.2	40	1.6	Acceptable Risk	Urgent Measure May Not Be Needed	187.2 (Design of barrier, parapet etc. that would prevent falls from the roof)
		Carrying roof insulation material		Falling Due To "Air-Step" On The Roof Edge	0.2	0.2	40	1.6	Acceptable Risk	Urgent Measure May Not Be Needed	
		Application of insulation material on the roof		Falling Due To The Breakage of Protective Barriers	1	0.5	40	20	Acceptable Risk	Urgent Measure May Not Be Needed	
		Placement of protective roof cover		Falling Due To Complete or Partial Collapse of Roof	0.5	0.5	100	25	Definite Risk	To Be Taken Under Action Plan	
	Installation and Maintenance of other Mechanic or Electronic System on the Roof	Carrying mechanic, electronic system materials and infrastructure materials		Falling Due to The Heavy Weight of Object in Hand on the Threshold	0.2	0.5	40	4	Acceptable Risk	Urgent Measure May Not Be Needed	
		Preparation of infrastructure Installation and assembly of system elements		Dropping Materials While Working on Threshold	3	3	15	135	Significant Risk	Closely Monitored, To Be Taken Under Annual Action Plan	

Comparison of Risk Scores for Primary Design Decisions and Secondary (Alternative) Design Decisions

Primary Design Decision		Secondary (Alternative) Design Decision		Variation in Risk Score (Mitigating Effect of Alternative Design on Risk Score)
Definition	Total Risk Score	Total Risk Score	Definition	Rate (%)
Design of exterior walls with bricks, blocks etc.	21620	2763.1	Exterior pre-cast Pannel wall system	87.22
No central system for air conditioning/ ventilation system etc.	1360	0	Central system for air conditioning/ ventilation system etc.	100
Incorrect design of barrier, parapet etc. that would prevent falls from the roof, or no design at all	4600	187.2	Design of parapet of barrier design on the roof	95.93

Finencial Comparison of Primary and Secondary Designs

Finential comparison has been performend for external Wall design Alternatives

Design Alternative 1 (Brick Wall 25cm thickness)		**Design Alternative 2 (Pannel Wall 25cm thickness)**	
Definition	**Unit Price (TRY/m²)**	**Definition**	**Unit Price (TRY/m²)**
Brick works	122	Pannel Wall	203
Plastering (inside)	45	workmenship	35
Plastering (Outside)	58	-	-
Lintel (Lento)	3	-	-
Jacketing	158	-	-
Total Unit Price	**386**	**Total Unit Price**	**238**

1.622

Work Done on REVIT and DYNAMO (H.I.S.)

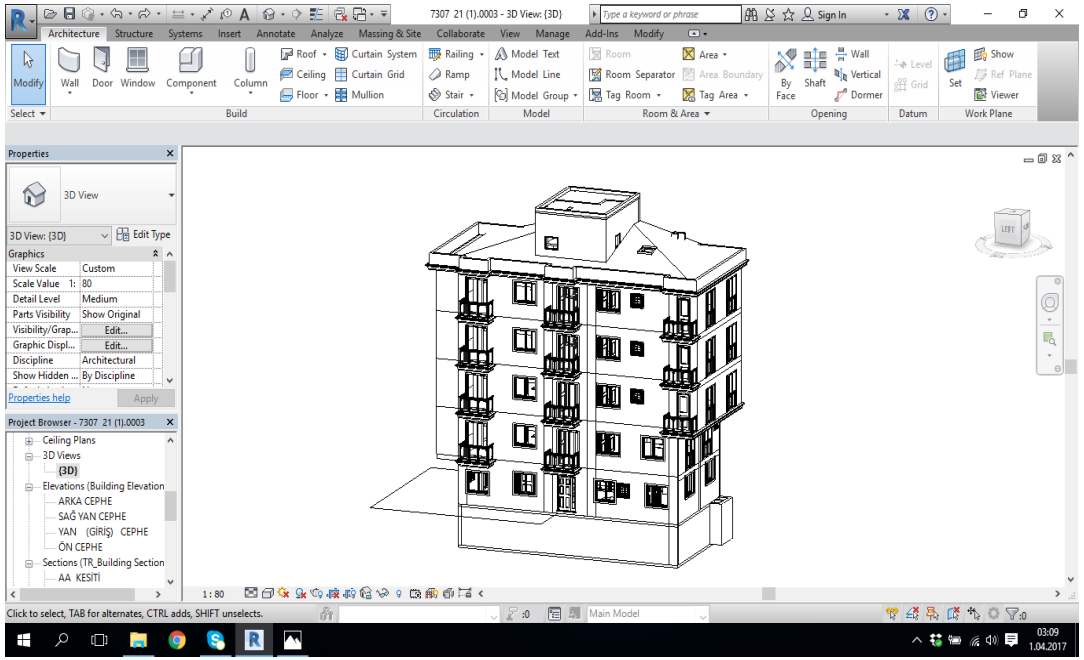
Very breafly;

A **software packege have been created** (by DYNAMO in REVIT) to;

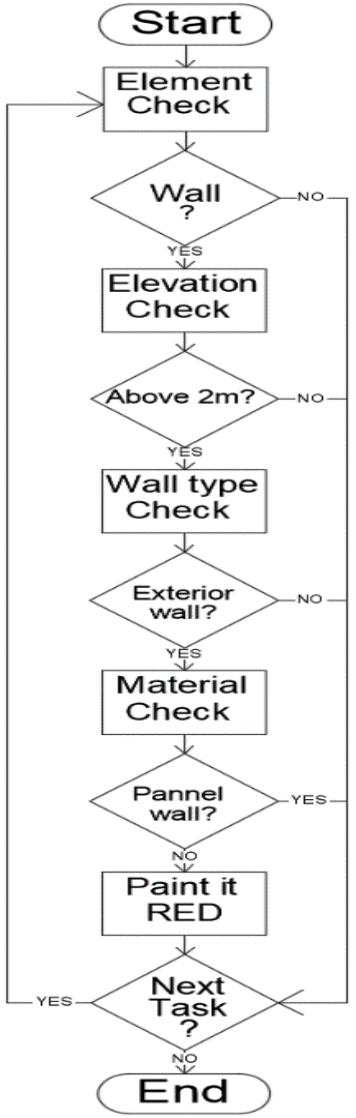
-**search all elements** of the building model

-**define** the **elements related with the primary design** decission (has high risk score)

-and **suggest secondary design decission** as safer design alternative.



Flowchart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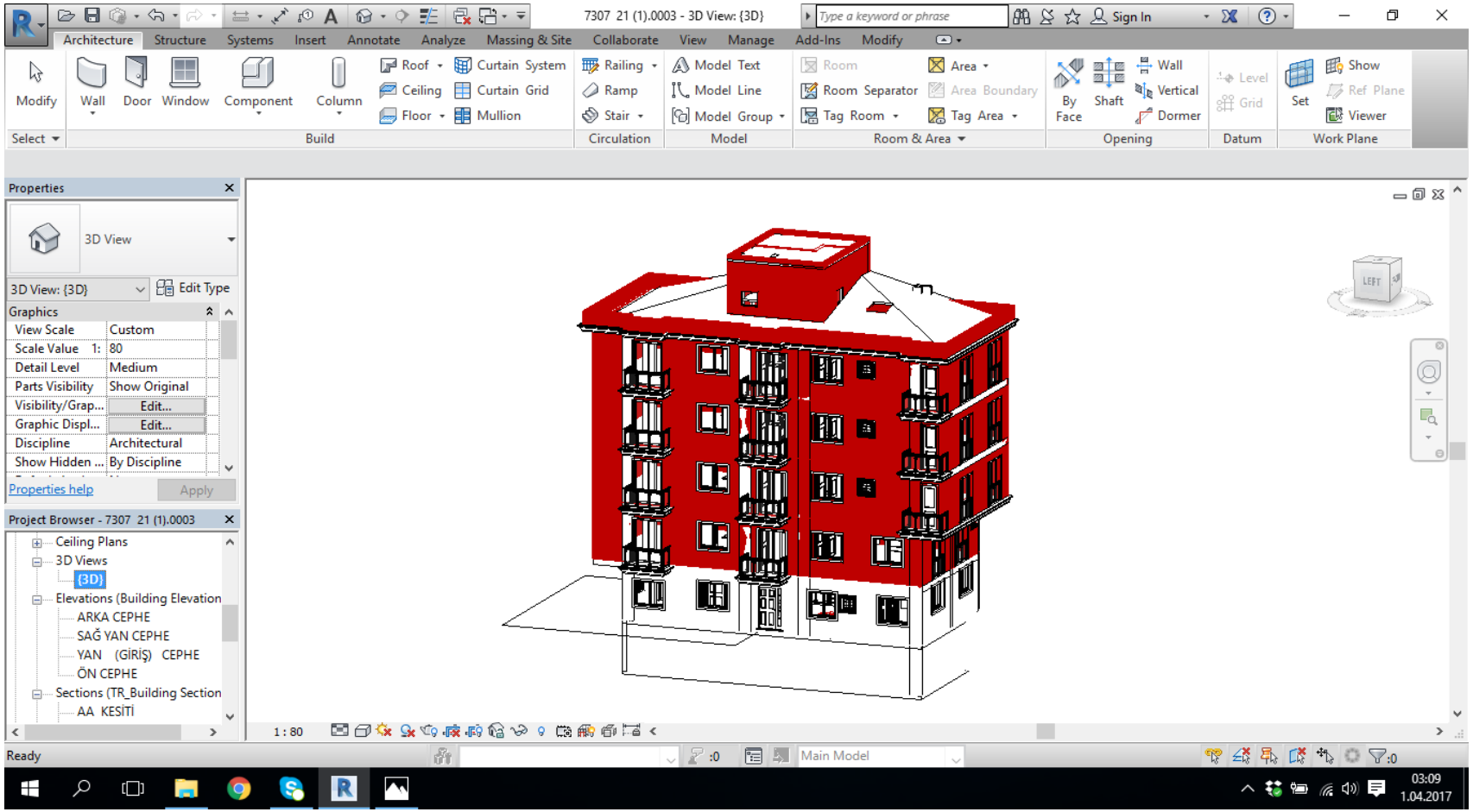
Element Check
Wall ?
NO
YES
Elevation Check
Above 2m?
NO
YES
Wall type Check
Exterior wall?
NO
YES
Material Check
Pannel wall?
YES
NO
Paint it RED
Next Task ?
YES
NO
End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Architecture
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Window
Component
Column
Roof
Ceiling
Floor
Curtain System
Curtain Grid
Mullion
Railing
Ramp
Stair
Model Text
Model Line
Model Group
Room
Room Separator
Tag Room
Area
Area Boundary
Tag Area
By Face
Shaft
Wall
Vertical
Dormer
Level
Grid
Set
Show
Ref Plane
Viewer
Select
Build
Circulation
Model
Room & Area
Opening
Datum
Work Plane
Properties
3D View
3D View: {3D}
Edit Type
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Sections (TR_Building Section
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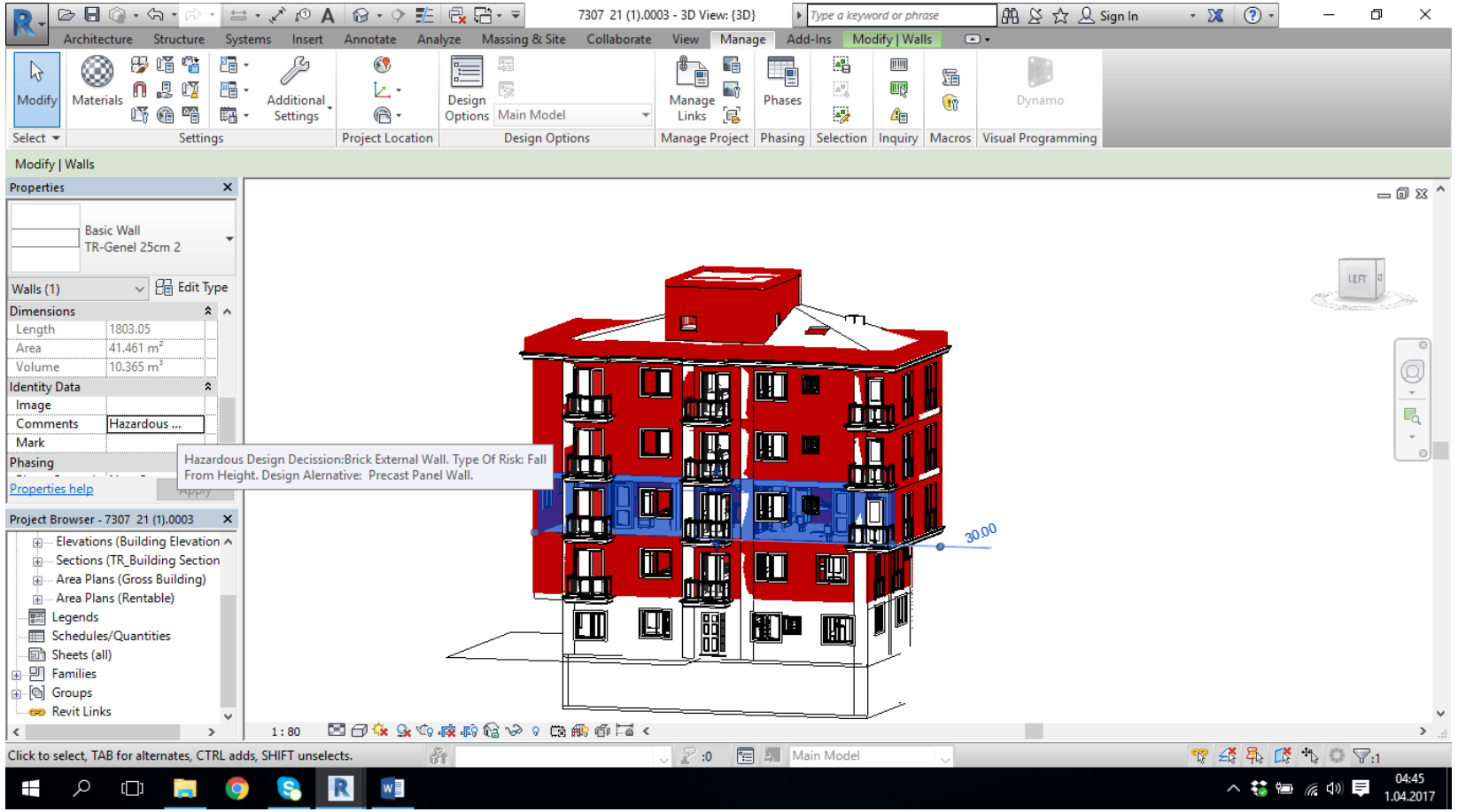
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Properties
Basic Wall
TR-Genel 25cm 2
Walls (1)
Edit Type
Dimensions
Length 1803.05
Area 41.461 m²
Volume 10.365 m³
Identity Data
Image
Comments Hazardous ...
Mark
Phasing
Properties help
Hazardous Design Decission:Brick External Wall. Type Of Risk: Fall From Height. Design Alernative: Precast Panel Wall.
Project Browser - 7307 21 (1).0003
Elevations (Building Elevation
Sections (TR_Building Section
Area Plans (Gross Building)
Area Plans (Rentable)
Legends
Schedules/Quantities
Sheets (all)
Families
Groups
Revit Links
30.00
1 : 80
Click to select, TAB for alternates, CTRL adds, SHIFT unselects.
Main Model
04:45
1.04.2017

Details...

Evaluation of Findings Generated **Through Data Classification**

- It can be seen that **793 occupational accidents of a total of 3004 accidents** happened in the **Construction industry** in TRNC, in 1994-2014 period. (**27% of Injuries** and **50% of Fatal** accident)
- In Construction industry, **'falls'** type of accidents **take the first place** for **frequency**, resulting in **death** and **injury**.
- **Falls type accidents** are examined in detail and **divided into three groups** as, '**falls from scaffolds**', '**falls from structural elements**', '**other type of falls**'.

Evaluation of **Activities Conducted on Revit**

- Work done in **REVIT** are **very important** in order to **make** the **study findings visible** and **contribute** the **sector** with the **study outputs**.
- With the revit model, the **relation** between the **primary and secondary design decisions** were **introduced** into the real life.
- The **choice of Revit** for this study was an **appropriate decision** since it is the **most used BIM software** in the country and region.

CONCLUSION

- All accident records have been collected, ordered and classified according to the standard of ICD-10 Codes.
- The relationship between the most critical accidents, design decisions, construction elements and construction activities has been successfully ıdentified.
- Alternative design desigions have been suggested and their advantages have been demonstrated by a risk analysis.
- Finencial comparison of primary and secondary design have been performed. As a result of this, secondary (alternative) design found much more economical than the primary design.
- Performance of HIS has been evaluated by a case study and results showes that its performance is satisfying.

thank you for your time…

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