MANAGING QUALITY IN FIRE SAFETY DESIGN PROJECTS INVOLVING RSET ANALYSES

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Abstract. The building regulations in many countries allow a performance-based design for fire safety. Such regulations permit the fire safety designer to adopt engineering methods to derive the fire safety design of, for example, a building. In verifications related to life safety, a fire safety designer may make use of a computer evacuation model in a quantitative assessment of the identified design evacuation scenarios. However, as the reliance on evacuation modelling, number of models and complexity increases, there is even more of a need for a systematic means of ensuring quality in evacuation assessments than before. In this paper, a template summary sheet and a complementing tool are presented, both of which are believed to facilitate, encourage and ensure quality management in fire safety design projects involving RSET analyses. In addition, the use of these tools is exemplified in a simple case study using the computer evacuation model Pathfinder.

1 Introduction

In the past, the fire safety design of a building relied heavily on detailed specifications in national, regional or local prescriptive building regulations [1]–[3]. These specifications prescribed how the building should be designed from a fire protection perspective in order for it to be approved by the authority having jurisdiction. Furthermore, the regulations gave little or no room for engineering approaches to verify the design. Today, most regulations are still based on prescriptive solutions. However, in many countries, they have been developed to allow for a performance-based design of the fire safety [4], [5]. One of the largest advantages of such regulations is that they permit the fire safety designer to adopt engineering methods to derive a design that is equal to (or better) than the design resulting from the prescriptive specifications, possibly to a lower cost. In addition, they allow unique features and uses of a building to be addressed to a larger extent than before.

Designing fire safety using a performance-based approach requires expertise in areas such as fire dynamics and the potential effects on the building, occupant behaviour and in fire rescue service operations [4]. Thus, methods and processes need to be applied in order to ensure the validity and reliability of the design, both regarding the fire safety design process and the engineering analyses. For the former, the Society of Fire Protection Engineers has developed a performance-based design process which essentially consist of the following steps [5]:

- Define project scope
- Identify goals
- Define stakeholder and design objectives
- Develop performance criteria
- Develop design fire scenarios
- Develop trial designs
- Evaluate trial designs
- Select the final design
- Document the design

Assuming that the goal is protection of life safety, performance criteria are likely to be defined as threshold values related to temperature, smoke, gas concentrations, visibility, and etcetera. Different trial design alternatives can then be evaluated towards the performance criteria. Typically, this is preceded by a risk identification that aims to identify all the possible fire scenarios that can occur given the project scope [6]. The most relevant fire scenarios are then selected to represent design fire scenarios. Similarly, different occupant scenarios are identified and selected to represent design occupant scenarios [7].

The type of evaluation that is carried out is dictated by the project scope, and is typically either qualitative or quantitative. More specifically, the analysis can vary in complexity from simple qualitative reasoning to a full quantitative risk analysis (QRA), depending on the project scope [8]. Two quantitative evaluation approaches that are often adopted in performance based design are deterministic analysis and probabilistic analysis. Deterministic analysis (also known as scenario analysis) involves the selection and analysis of a manageable number of scenarios that represent the worst credible fire and evacuation cases. This means that the hazards are mainly described in terms of their consequences in the deterministic analyses. Probabilistic analysis instead involves identification and analysis of the full range of possible scenarios, and the scenarios are then described in terms of their probability and consequence.

Independent of the quantitative approach, computer evacuation models for buildings, i.e., evacuation simulators, are typically used to assist the fire safety designer in the evaluation of the trial designs. Although the models are very valuable in quantifying evacuation processes, they still represent relatively basic engineering tools that are dependent on the user inputs. In other words, they provide little understanding of human behaviour in fire [9], and may yield optimistic or even unrealistic assessments of required safe escape times (RSET) due to, for example, default model settings or model uncertainties [10], [11]. In addition, the number of computer evacuation models, as well as their complexity, have increased rapidly in the past [12], [13]. Reasons being mentioned for this are related to technological developments, a demand for models that can cope with more complex building designs than before as well as the need to address problems other than fire. In particular, the increased complexity of the models have amplified the need to transparently document assumptions made in the trial design evaluation of the design occupant scenarios, which typically is expressed as computer evacuation model inputs. In addition, the development has stressed the need for well-developed, effective and operational routines for managing quality in fire safety design projects involving RSET analyses with help from computer evacuation models.

1.1 Quality management

Most companies are certified to quality management systems such as ISO 9000:2015 [14]. Key components of such systems are quality management and traceability, where the former is explained to include:

> *[…] establishing quality policies (3.5.9) and quality objectives (3.7.2), and processes (3.4.1) to achieve these quality objectives through quality planning (3.3.5), quality assurance (3.3.6), quality control (3.3.7), and quality improvement (3.3.8).* [14]

Thus, a company certified to such a quality management system must define both quality objectives and operational processes to achieve these. Among other things, this means establishing processes for quality control. As a practical example, that can be done by establishing one or more generic routines or guidelines for how to ensure the quality of produced documents. Such a process is deemed important in a society where the competition in the market is high. Furthermore, processes for ensuring quality is not only important in order to fulfil clients' expectations, but they are also important for organizational learning and development.

Typically, processes for quality control involves two key terms: a) *self-inspection* and *internal review*. In fire safety engineering, this often means that the designer is required to check his/her own work (= self-inspection) before it is reviewed internally (= internal review). The purpose is to ensure that the derived design is consistent with the overall project scope and the design objectives. Furthermore, an internal review needs to be performed by a qualified colleague who is well-informed about the project, but who is independent of the actual design being reviewed, before it can be accepted and delivered to the client.

1.2 Practical implications for RSET analyses with a computer model

A typical fire safety design goal is protection of life safety. If the design is performance-based, the fire safety designer may make use of a computer evacuation model in a quantitative assessment of the identified design evacuation scenarios. As the number of computer evacuation models, as well as their complexity, have increased rapidly in the past, there has been a growing need to specify the above-mentioned generic routines for ensuring quality for RSET calculations. In line with the discussion above, such a routine should involve a well-developed, effective and operational process for self-inspection and internal review.

During the summer of 2016, work was undertaken at WSP Sverige AB in order to improve quality management in fire safety design projects involving RSET analyses with help from computer evacuation models. Central for this work were the terms introduced above, more specifically: self-inspection and internal review. The purpose of the work was to develop an effective and operational routine for managing and ensuring quality in fire safety design projects involving RSET analyses with computer evacuation models. The objective of this paper is to share the results of this work, which is:

1. a template summary sheet that can be used to summarize a RSET computer evacuation model, and
2. a tool that can be used to facilitate both self-inspection and internal review of that computer evacuation model.

It should be noted that work similar to the one presented in this paper have been presented elsewhere. Kuligowski [13] do, for example, present a user checklist of factors and issues that computer evacuation model users should address when selecting and configuring a model. In addition, the fire safety consultancy firm Briab Brand & Riskingenjörerna AB has developed a thorough practical guideline on evacuation assessments, which includes questions to be checked during such analyses [15]. These references have been used as inspiration for the work presented in this paper.

1.3 Acknowledgements

The work presented in this paper was essentially executed by a summer intern at WSP Sverige AB, more specifically Mr. Johan Askman. Therefore, the authors would like to thank Mr. Johan Askman for his contribution, which ultimately led to this paper. In addition, the authors would like to thank WSP Sverige AB for the funding, which made the work presented in this paper as well as the documentation of it possible.

2 Tools for ensuring quality in RSET analyses with a computer model

As mentioned above, the development of a routine for managing and ensuring quality in fire safety design projects involving RSET analyses with computer evacuation models rendered a template summary sheet, and a tool to facilitate self-inspection and internal review. These two products were mainly developed for the computer evacuation model Pathfinder [16]–[18], which in this paper is used in a case study for demonstration purposes. Therefore, some terms are directly linked to Pathfinder, and may not be directly applicable to another computer evacuation model.

The template summary sheet can be described to be a simple MS Word document separated into a number of sections (see Figure 1 for a snapshot illustrating the template summary sheet, section four):

1. General information about the project
2. Drawings and other similar references on which the model is based
3. Basic information about the design occupant scenarios
4. Input parameters

The idea is that the template summary sheet should be filled out before and during the simulation process. Providing basic information about the design occupant scenario and the input parameters used in the simulation implicitly forces the designer to go through the model and document it thoroughly while model assumptions are made, and he/she still have them fresh in mind. This is good for at least two reasons. Firstly, a transparent presentation of the model is made available not only in the model itself (represented by the model file), but also in written text. In other words, it can be included as an appendix to a life safety verification report, which means that the model basics can be reviewed by someone who lacks access to the actual model file or the computer model that was used. Basically, the summary sheet should contain enough information so that someone else could reproduce the model, yielding the same output. Secondly, the documentation process works as a self-inspection of the built model. By going through the input parameters, the designer may become aware of mistakes made in, for example, connections regarding assumptions about flow rates of people, and etcetera.

Input parameters – ***Developed for Pathfinder, remove or leave non relevant rows empty when using another model*** *When multiple model ID's are included, insert separate rows only where the parameter differs between the models (see example in 1.02: Time Limit)*				
#	**Parameter**	**Value**	**Unit**	**Comment/Justification**
1.13	*Save Restart Files*		-	
1.14	*Snapshot interval*		s	
1.15	*Curve error*		-	
1.16	*Face error*		-	
2	**Profile: Disabled**			
2.01	*Priority Level*		-	
2.02	*Speed*		m/s	
2.02.01	*Level Terrain: Speed*		m/s	
2.02.02	*Level Terrain: Speed-Density Profile*		-	
2.02.03	*Stairs: Speed Fraction Up*		-	
2.02.04	*Stairs: Speed-Density Profile Up*		-	
2.02.05	*Stairs: Speed Fraction Down*		-	
2.02.06	*Stairs: Speed-Density Profile Down*		-	
2.02.07	*Ramps: Speed Fraction Up*		-	

Figure 1. Example of contents in the template summary sheet.

Although the template summary sheet may provide an internal reviewer with information about the model, the sheet itself is not deemed to be enough for a proper internal review to ensure quality according to what was describe in the introduction to this paper. To complement the summary sheet, a simple documentation tool was developed in MS Excel. This tool contains five different worksheets to not only facilitate self-inspection and internal review of a RSET calculation, but also the documentation of it. The five worksheets can be described as follow:

1. General information about the tool
2. Basic model assumptions
3. Verification and model inspection and control
4. Life safety verification inspection and control
5. Final remarks of inspection and control

In the second worksheet, the designer needs to answer the following three questions for each of the simulations/models that have been run:

1. Has an optimal evacuation been assumed? The term optimal evacuation here refers to an evacuation in which all occupants are evenly distributed among the evacuation routes as defined in the trial design, i.e., to produce the lowest possible RSET. Thus, implicitly taking the flow rate restriction of the connections into consideration.

2. Do the agents move directly to an exit? The term directly to an exit here refers to an evacuation in which all occupants move directly to an exit, without passing specified markers in the model.
3. Is Steering mode used together with individual door flow rate limitations? The term Steering mode with individual door flow rate limitations here refer to the behaviour mode used in Pathfinder together with how movement through doors are being treated in the model.

If the designer answers no to any of these questions, he/she is required to explain and justify why in written text, which then can be reviewed by the internal reviewer. As an example, a designer may force the agents in a model to move through certain rooms to simulate a searching behaviour, i.e., a behaviour that Pathfinder is not able to simulate by default. Since this type of modification to the model defaults will affect the results, it is essential that the justification for it be documented and transparently presented to the internal reviewer. It should be noted that the choice of questions partly have been dictated by praxis, i.e., how life safety verifications typically are performed in Sweden. As an example, the Swedish regulations recommend designers to manually limit the flow rate in door connections, stairs, and etcetera.

In the third worksheet, the designer needs to answer around 30 yes/no-questions about the simulation in general, and the input parameters in particular. As an example, he/she needs to answer if representative pre-movement times have been assumed given the trial design, and if they have been correctly implemented in the model. Furthermore, he/she also needs to answer if they have been correctly represented in the model. There is also room for comments after each question, see Table 1 for an example of how this has been implemented in the tool. It should be noted that Table 1 has been transformed to better match the format of this paper, and the content has been translated from Swedish.

Table 1. Partial example of the layout of the tool to facilitate self-inspection and internal review.

Population, profiles and behaviours	**Designer response**	**Comment**	**Internal reviewer response**	**Comment**
Have representative assumptions been made regarding pre-movement times?				
Have selected pre-movement times been correctly implemented in the model?				
Have selected pre-movement times been correctly represented in the model?				

In the fourth worksheet, the designer is faced with another around 15 questions about the documentation of the RSET calculation. The questions varies from formal questions about if correct project details have been specified, to questions regarding whether or not the project scope, trial designs, and etcetera, have been clearly presented. Finally, in the fifth worksheet, the internal reviewer is given the opportunity to leave his/her final comments about his/her total impression of the RSET calculation, both in particular and in relation to the project scope. In addition to this, the internal reviewer is also provided with the ability to answer and comment on each of the questions in worksheet 2-4 as described above. In all essence, he/she is required to complete the same yes/no-questions as the designer and can also leave a comment in relation to each question.

Altogether, the template summary sheet and the Excel worksheets are believed to encourage and facilitate self-inspection and internal review for the reasons mentioned above. Furthermore, the review can be clearly documented in a consequent manner between different projects. Thereby, the tools are deemed to be good and valuable parts of a company's overall processes for quality control.

3 Case study: Application of the tools for a simple RSET calculation using Pathfinder

In this section, a simple RSET case study model is used to exemplify how the template summary sheet and the Excel worksheets may be filled out by a fire safety designer during a RSET calculation. The purpose is to illustrate the use and benefit of the two tools, i.e., the template summary sheet and the MS Excel tool. The case has for that reason been kept very simple in terms of geometry and features used in the software.

3.1 Case description

The case is fictional and consists of a building with an assembly hall located on the second floor of the building. The floor area is 400 m^2 (25x16 meters), and it can be accessed through two main entrances. Both entrances consist of stairs with 2 meters width, and the can also be used as evacuation routes in case of fire. The stairs' locations are illustrated in Figure 2. As the distance between the stairs is 16 meters they can be regarded as independent of each other (assuming they both lead to safe areas). Thus, the floor has such depth that a third evacuation route is necessary to fulfil the requirement of travel distance to the closest evacuation route in the Swedish building regulations [19]. The requirement can be fulfilled by installing a third stair in the back of the room.

If the case study building is an existing building, space may be a limiting factor. For the case study, it is, therefore, assumed that the third evacuation route consists of a spiral stair (which requires less space than a straight stair). It could even be an existing stair. However, spiral stairs do not meet the deemed-to-satisfy solution in this case, and therefore, an analytical approach is used to verify the arrangement. The focus of the case study is, however, not to verify the solution and an in-depth discussion regarding the appropriateness of spiral stairs is not presented in this paper. The main problem of using spiral stairs for evacuation within this paper is related to the limited flow rate of people using the stair. For the purpose of this study, a design value of 0.5 p/s has been used. This is approximately half the design value that a deemed-to-satisfy solution with straight stairs would generate (a 1.2 meter wide straight stair with a people flow of 0.9 p/s [20]). In this case study, the geometry of the spiral stair not been modeled. Pathfinder has the capacity of doing such a model, but since the flow rate values used in the design are known and selected from other references (in this case the Swedish building regulation), a flow rate restriction is equal the expected flow rate in the stairs applied to the door leading to the stairs.

A total of 4 scenarios were modeled, which would probably be sufficient for a comparative study between the trial design and the deemed-to-satisfy solution within a normal life safety verification. The four scenarios are:

1. All evacuation routes are accessible, the third evacuation route is a spiral stair
2. One main entrance is blocked for evacuation, the third evacuation route is a spiral stair
3. All evacuation routes are accessible, the third evacuation route is a straight 1.2 m wide stair
4. One main entrance is blocked for evacuation, the third evacuation route is a straight 1.2 m wide stair

In the case study, 99 % of the population is assumed to have a walking speed of 1.5 m/s. The rest are assumed to have a walking speed of 2/3 of the normal value, thus, taking movement and orientation disabilities into account. The approach is according to the Swedish building regulation recommendations [20]. The design number for the occupancy is assumed to be 200 people, thus, corresponding to a population density of 0.5 p/m^2.

Doors leading to the stairs at the main entrances have a total width of 2 x 1.2 meters. Flow through the stairs are therefore not expected to be restricted by the door flow rates. Doors at the end of stairs are modeled with the same width as the stairs, and should not restrict flows either. The scenarios are modeled using the Steering behavior model. No efforts are made to create behaviors other than evacuees could go to any exit.

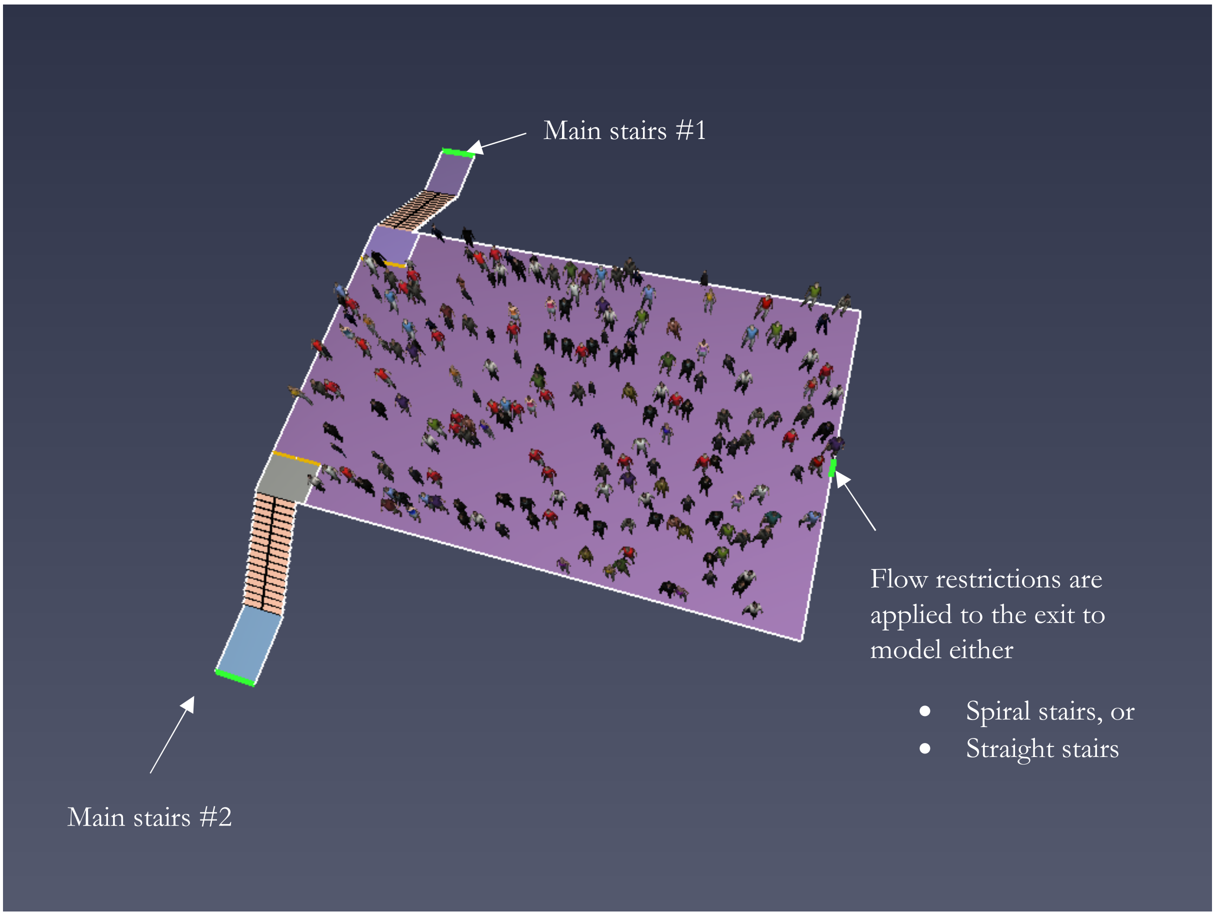


Figure 2. The case study model.

3.1.1 Self-inspection and internal review

The template summary sheet and the tool to facilitate both self-inspection and internal review resulting from the case study described above is illustrated in Figure 3 to Figure 7 and Table 2 to Table 3. Due to limitations given within the frameworks of this paper, the complete details resulting from the self-inspection and internal review cannot be included. It should be noted that model errors, as highlighted in the figures and tables below, are intentional to demonstrate the quality control mechanisms that the tools offer.

General information	
Project name:	FEMTC 2016 paper
Project number:	-
Study:	Case study for paper
Date started:	2016-10-10
Personnel	
Lead engineer(s):	Karl Fridolf
Evacuation modeller(s):	Daniel Rosberg
Reviewer(s):	Karl Fridolf
General project description:	Reconstruction of building to accomodate restaurant
Model description:	Life safety verification assuming evacuation through a spiral stair
Model purpose:	To verify if evacuation is satisfactory
Model file location:	-
Checking summary:	Checked by reviewer

Figure 3. General project information described by the fire safety designer in the summary sheet.

Drawings	
ID	**Drawing** ***Import drawings over the relevant model areas***
-	All made up • 16x25 sq m • 200 people • 2 main stairs, 2 m wide • 1 spiral stair

Tabell 3

Basic model information		
Model ID	**Scenario description**	**Time line** ***Highlight the most important times in the scenario (as an example, t = 60 s: Evacuation is initiated.)***
1	All stairs available for evacuation	Only movement time modeled
2	One of the main stairs is blocked for egress	Only movement time modeled
3	As #1, but spiral stair is replaced by a 1.2 m straight stair	Only movement time modeled
4	As #2 (one of the main stairs blocked by fire), but spiral stair is replaced by a 1.2 m straight stair	Only movement time modeled

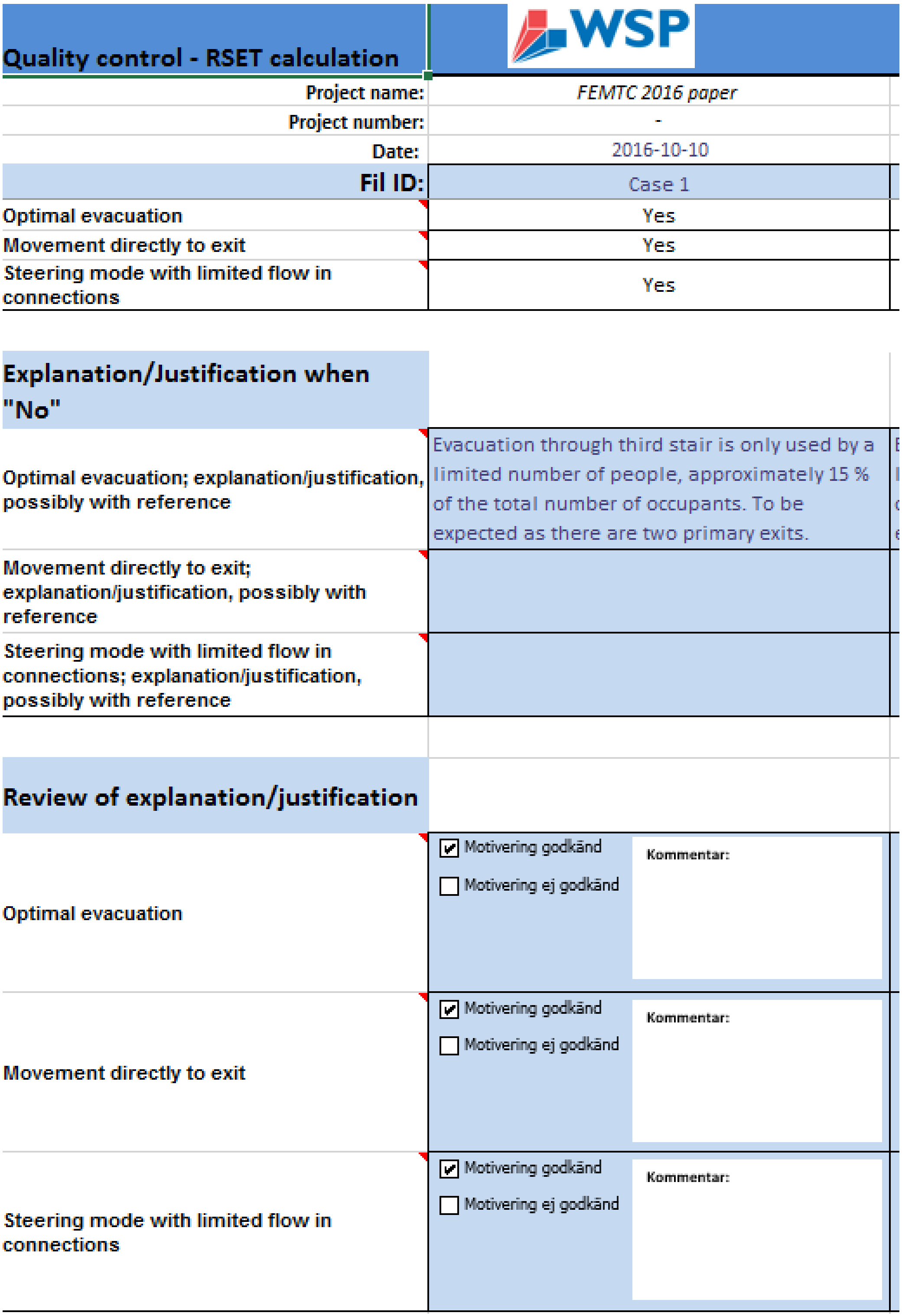
Figure 4. Drawings and basic model information described by the fire safety designer in the summary sheet.

Input parameters – ***Developed for Pathfinder, remove or leave non relevant rows empty when using another model*** *When multiple model ID's are included, insert separate rows only where the parameter differs between the models (see example in 1.02: Time Limit)*				
#	**Parameter**	**Value**	**Unit**	**Comment/Justification**
5	**Key geometry connections (doors etc.)**			
5.01	*Door to third exit*			
5.01.01	*Model ID 1: Spiral stair*	*0.8*	m	Standard door width
5.01.02	*Model ID 2: Spiral stair*	*0.8*	m	Standard door width
5.01.03	*Model ID 3: Straight stair*	*1.20*	m	Standard door width
5.01.04	*Model ID 4: Straight stair*	*1.20*	m	Standard door width
5.02	*Doors to main stair #1*	2 x 1.2	m	According to architectural drawings
5.03	*Doors to main stair #2*	2 x 1.2	m	According to architectural drawings
5.04	*Main stair #1*	2.0	m	According to architectural drawings
5.05	*Main stair #2*	2.0	m	According to architectural drawings
5.06	*Exit doors at level +0 m @Main stairs #1*			
5.06.01	*Model ID 1: Available*	2.0	M	Same as stair width. Will not restrict flows.
5.06.02	*Model ID 2: Unavailable*	-	M	Blocked for egress (Disabled in model)
5.06.03	*Model ID 3: Available*	2.0	M	Same as stair width. Will not restrict flows.

Figure 5. Selection of input parameters regarding key geometry connections described by the fire safety designer in the summary sheet.

Input parameters – ***Developed for Pathfinder, remove or leave non relevant rows empty when using another model*** *When multiple model ID's are included, insert separate rows only where the parameter differs between the models (see example in 1.02: Time Limit)*				
#	**Parameter**	**Value**	**Unit**	**Comment/Justification**
6	**Flow rates**			
6.01	*Door to third exit*			
6.01.01	*Model ID 1: Spiral stair*	*0.5*	p/s	Door flow restrictions are equal to flow restrictions in stairs (spiral) for easier modelling (no need to model the actual spiral stairs)
6.01.02	*Model ID 2: Spiral stair*	*0.5*	p/s	Door flow restrictions are equal to flow restrictions in stairs (spiral) for easier modelling (no need to model the actual spiral stairs)
6.01.03	*Model ID 3: Straight stair*	*0.9*	p/s	Door flow restrictions are equal to flow restrictions in stairs (spiral) for easier modelling (no need to model the actual spiral stairs)
6.01.04	*Model ID 4: Straight stair*	*0.9*	p/s	Door flow restrictions are equal to flow restrictions in stairs (spiral) for easier modelling (no need to model the actual spiral stairs)
6.02	*Doors to main stair #1*	2.31	p/s	Door flow restrictions according to BBRAD3
6.03	*Doors to main stair #2*	2.31	p/s	Door flow restrictions according to BBRAD3
6.04	*Main stair #1*	1.7	p/s	Stair flow restrictions according to BBRAD3
6.05	*Main stair #2*	1.7	p/s	Stair flow restrictions according to BBRAD3

Figure 6. Resulting flow rates in key geometry connections described by the fire safety designer in the summary sheet.



Quality control - RSET calculation	WSP
Project name:	*FEMTC 2016 paper*
Project number:	-
Date:	2016-10-10
Fil ID:	Case 1
Optimal evacuation	Yes
Movement directly to exit	Yes
Steering mode with limited flow in connections	Yes
Explanation/Justification when "No"	
Optimal evacuation; explanation/justification, possibly with reference	Evacuation through third stair is only used by a limited number of people, approximately 15 % of the total number of occupants. To be expected as there are two primary exits.
Movement directly to exit; explanation/justification, possibly with reference	
Steering mode with limited flow in connections; explanation/justification, possibly with reference	
Review of explanation/justification	
Optimal evacuation	☑ Motivering godkänd ☐ Motivering ej godkänd Kommentar:
Movement directly to exit	☑ Motivering godkänd ☐ Motivering ej godkänd Kommentar:
Steering mode with limited flow in connections	☑ Motivering godkänd ☐ Motivering ej godkänd Kommentar:

Figure 7. Basic model assumptions described by the fire safety designer and checked by the internal reviewer in the review tool. The terms "Motivering godkänd" and "Motering ej godkänd" means "Motivation accepted" and "Motivation not accepted".

Table 2. Verification and model inspection and control performed by the fire safety designer and the internal reviewer in the tool. It should be noted that the table has been transformed to better match the format of this paper, and the content has been translated from Swedish.

Model				
Geometry	**Designer answer**	**Designer comment**	**Reviewer answer**	**Reviewer comment**
Is the correct scale used during import of drawing and are model openings replaced by exits?	Yes		No	Main floor area is not correctly represented (< 400 m^2). Please double check.
Is the correct height used between the floor plans?	Yes		Yes	
Are doors, stairs and other connections widths correctly defined?	Yes		Yes	
Door and other connections (excl. stairs)	**Designer answer**	**Designer comment**	**Reviewer answer**	**Reviewer comment**
Has the effective door width been taken into account?	Yes	Modelled per default.	Yes	
Has the correct capacity been defined?	Yes	Implicitly delimited by other bottlenecks. Not explicitly defined, but based on Steering mode defaults.	No	Flow rates have been limited in bottlenecks (stairs), and unlimited in other connections/doors. However, there's a discrepancy between the description of the model input in the summary sheet, and in the models. In addition, calculation of flow rate capacities in summary sheet does not correspond to BBRAD3 recommendations. See, for example, 6.02-6.03. Please double check.
Has a sensitivity analysis been executed with half/full blockage of some doors?	Yes	Scenarios with one blocked main exit is studied.	Yes	
Has capacity been defined differently for known/unknown exits?	Yes	Third stair accounts for less people than main exits.	Yes	In terms of number of people using different exits, however, not in terms of flow rate restrictions. Deemed not necessary for this analysis.
Stairs	**Designer answer**	**Designer comment**	**Reviewer answer**	**Reviewer comment**
Has the effective stair width been taken into account?	Yes	Modelled per default.	Yes	
Has the correct capacity been defined in each top/bottom door to the stair?	Yes	Delimited in top door to main stairs and in exit to third stair.	No	Flow rate restriction at top doors to stairs have not been correctly defined and deviates from summary sheet. Seems to be correct in the summary sheet, but based on free and not effective width in the model. Please double check.
Is the walking speed adjusted in stairs compared to horizontal areas?	Yes	Modelled per default.	Yes	
Population, types and behaviour	**Designer answer**	**Designer comment**	**Reviewer answer**	**Reviewer comment**
Has representative pre-movement times been assumed?		Not modelled		

Model				
Geometry	**Designer answer**	**Designer comment**	**Reviewer answer**	**Reviewer comment**
Has representative pre-movement times been correctly implemented in the model?		Not modelled		
Have different pre-movement times been used for different groups?		Not modelled		
Have representative movement speeds been assumed?	Yes	According to BBRAD3.	Yes	Speeds in stairs are based on SFPE's hydraulics model (Pathfinder default). Deemed appropriate.
Have representative movement speeds been correctly implemented in the model?	Yes		Yes	
Have different movement speeds been used for different groups?	Yes		Yes	
Have the population density been assumed to affect the movement speed in the model?	Yes	Modelled per default.	Yes	
Have people with disabilities been considered in the model?	Yes	1% have a lower walking speed	Yes	
Has the correct number of people been assumed in the model based on information from the client/regulations?	Yes	Value of 200 people is based on BBR19.	Yes	
Has the maximum allowable population density been defined in the model?	Yes	Based on CD = 0.08 m.	Yes	Yes, based on comfort distance of 0.08 m. Equal to 4 p/m2 max in queues. However, it seems a bit high, please double check.
Has the awareness of different exits been taken into account in the model?	Yes	Implicitly by less people using third stair.	Yes	
Has a sensitivity analysis been executed based on knowledge of available exits?	No	No specific analysis has been executed. The case with a blocked main stair may represent such a case.	No	Deemed not necessary for purpose with model.
Has a sensitivity analysis been executed based on the number of agents in the model?	No		No	Deemed not necessary for purpose with model.
Output	**Designer answer**	**Designer comment**	**Reviewer answer**	**Reviewer comment**
Have pre-movement times been correctly represented in the model?		Not modelled		
Have flow rates in doors and other connections been correctly represented in the model?	Yes	Checked against flow restrictions.	Yes	Seems about right. Flow rates are typically lower than normal design values, but this is due to the queueing situation which is a result of the stair bottleneck.
Have flow rates in stairs been correctly represented in the model?	Yes	Checked against flow restrictions.	No	Stair flow rates in main stairs are lower than defined values in the summary sheet and in the model input. Please double check.
Have population densities been checked in areas where queuing arises?	No	High population densities not expected.	Yes	Checked for case 1. Corresponds to defined maximum value.

Table 3. Final remarks of inspection and control performed by the internal reviewer in the tool. It should be noted that the table has been transformed to better match the format of this paper, and the content has been translated from Swedish.

Reviewer final comments	Overall impression is that model represents the project purpose. A number of discrepancies between model description, input and output were defined. Please double check and, if necessary given the results, rerun model. Particularly check: main floor area, door flow rate description in summary sheet and how it's represented in the model, flow rate restrictions in stairs and maximum allowable population density.
Need for future correspondence	A reply confirming that the above identified discrepancies have been treated.
Need for a new review	Not necessary.

4 Conclusion

In this paper, a summary sheet and a complementing tool to facilitate quality management in fire safety design projects involving RSET analyses has been presented. These tools are believed to both facilitate and encourage self-inspection by making the fire safety designer document his/her work during the life safety verification process. In addition, they contribute to making assumptions and limitations clear, which contributes to an efficient internal review.

The content presented in this paper, in particular the content of the summary sheet and the complementing tool, should not be treated as final or complete versions guaranteeing the quality control of any project. Rather, the content should be treated as a suggestion, which can be modified based on input and experiences from other people and models. The tools should be periodically reviewed and developed as a part of a commitment to continuous improvement and incorporating lessons learnt from projects.

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