How and to what extent can fundamental principles of conventional fire protection and sound insulation used to elaborate opening mechanisms in an architectural kinetic system responsive to ephemeral spatial demand?

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1. ABSTRACT

Demand responsive kinetic architecture can be a solution to more efficient use of scarce space and the closing mechanism between different functions is the key to implement such systems in the built environment of the future. This report takes precedents in smoke-protection doors, fire-protection systems and sound isolation systems in order to create a framework of knowledge to propose and engineer closing mechanisms in moving systems. Different seal types, built-up of various systems and their underlying physical principles were analysed regarding their workability, durability and maintenance in a kinetic system. While the general underlying physical principles of most existing systems can be directly translated to a kinetic system, it is observed that owed to higher mechanical straining and reduced accessibility in case of maintenance some seal types are inadvisable and cross sections and frame sizes might to be increased significantly.

Keywords: kinetic architecture, fire protection, smoke protection, sound insulation, seals, structural frames

2. INTRODUCTION AND RELEVANCE FOR A KINETIC SYSTEM

The idea of kinetic architecture responsive to ephemeral spatial demands dates far back and has numerous, mostly theoretical antecedents, from moving elements in the works of Gerrit Rietveld over Cedric Price´s fun palace to the variable housing block *OnTheGo* by The Why Factory.[1]

While there are numerous theoretical examples but little built precedence of such kinetic systems, there is no built paradigm for demand responsive kinetic systems that react to ephemeral needs of different users and user groups, and the theoretical examples fail to convince owed to lack of technical elaboration. Space enclosing elements as needed to segregate different uses whatsoever require very specific characteristics in terms of fire and smoke protection, thermal insulation and acoustic isolation, accumulated in the most important and most vulnerable part of the system: the locking mechanism.

The aim of this report is to facilitate the substantiated implementation and technical elaboration of further attempts to develop propositions for demand responsive kinetic architecture and especially the closing mechanisms these systems would require by creating a framework of understanding of existing components, systems and principles from related fields such as sound insulation and fire and smoke protection. This paper shall be seen as a guideline for

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[1] Maas and Fernandez, *OnThe Go Adaptable Housing*.

future architects attempting to propose systems with movable space enclosing elements, wo intend to substantiate their propositions by elaborating the technical framework of their theoretical concepts.

3. METHODOLOGY

In order to find these underlying principles, case studies and specific details, the process of primary selection and narrowing down of the analysed precedence has been of a heuristic and sometimes disappointing nature: They have been selected within a certain framework according to parameters such as resistance, neatness of the system and materiality and according to other less measurable parallels such as similarity in appearance or purpose of use. A more profound analysis of different systems by different manufacturers has then ben used to understand the underlying physical and functional principles of the case studies, their components and the different levels of performance of individual components. After finding and analysing these interdisciplinary analogies, their underlying principles and biography - as described by Ray Lucas - onto the general problematics the case studies and their components would face in a kinetic system, analysing their workability, durability and anticipated maintenance in that specific environment.[2]

The objective of this somewhat cross-disciplinary case study analysis based on a heuristic selection process is to take advantage of antecedent technical achievements – certified and working systems of fire protection and sound insulation – in order to provide a legit and - to an extent - proven design and engineering framework.

4. DEFINITION OF A TECHNICAL GOAL

As above mentioned, the prerequisites for sound isolation, heat insulation and fire protection of existing space-enclosing elements have been used in order provide this design guideline for the closing mechanisms for described systems. To provide a generic statement or guideline whatsoever the most contrary functions should be considered in such a system and hence it was necessary to review systems and components up to the highest standard of heat insulation, fire resistance and sound isolation, following in the choice of precedents the guideline for passive house standard in Germany (U=0,15 W/m²K, openings: 0,8 W/m²K)[3], f 90 fire protection standard for building class 5 and the sound isolation requirements for separated building components specified as in DIN 4109 (air: R = 54 dB, vibration: L = 53 dB)[4].

5. ANALYSIS EXISTING ELEMENTS IN THE SAME FIELD

<u>SMOKE PROTECTION DOORS</u>

The primary requirement of a smoke protection door, other than a fire protection door, is imperviousness towards air flow and hence smoke up to 200°C, which of course entails the need for a system with circumferential casket both entirely neat in itself and neatly connecting to the building component the opening is situated in. While the top and the sides of the opening always connect to a rebate and allow the placement of a seal that will be subject to compression only, the lower seal has to resist more physical contact and multidirectional

[2] Lucas, *Research Methods for Architecture*.
[3] Passivhaus Institut, “Kriterien Für Den Passivhaus-, EnerPHit- Und PHI-Energiesparhaus-Standard.”
[4] Rast, “DGfM-Merkblatt zum Schallschutz nach DIN 4109.”

forces, especially if a flush transition from one space to the other is required. We can generally distinguish between 3 different seal types that function due to these requirements: A sliding seal with contact threshold, a drop-down seal and the abovementioned seal with a rebate.

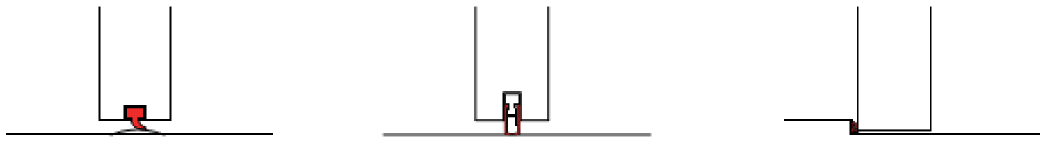

Figure 1: The three seal types: sliding seal, drop-down seal and rebate seal

Sliding seal with contact threshold

While the sliding seal thanks to its flexibility and excess of material seems like a perfect fit to the bottom threshold even under occurrence of irregularities, this capacity is gravely diminished during the aging process of the mechanism. The forces caused by the movement of the opening are almost perpendicular to its mounting bracket and structure of the seal which in the course of material fatigue and hence decreased flexibility will result in deformation of the seal and diminish its closing capacity and neatness.[5]

While such a damage is as minute as anticipated and the seal can be easily replaced in a conventional door system, the maintenance in a kinetic system might be of a different nature and the seal not easily accessible. With the threshold another component of potential damage is added to the system at the lower part of the system where thanks to gravity the strongest forces will occur.

Drop-down seal

The drop-down seal is moved into place by a spring powered mechanism triggered by the closing of the opening. Other than the sliding seal the drop-down seal moves vertically in the direction of its mounting and structure, which also thanks to gravity and tolerance of the vertical movement results in better closing capabilities even after aging and resulting reduced flexibility of the material. But while the delicate mechanism and the flexible seal of a smoke protection door can be easily exchanged in case of damage, which is usually expected within few years of use, it might not be easily accessible in a kinetic system.[6]

Compression seal with a rebate

Implementing a rebate allows the use of a compression seal in the direction of movement of the opening. In consequence the weight of the opening will never be laid upon the seal, not even owed to unprecise execution or aging of the whole structural system.

The seal itself is solely subject to compression and even in case of aging or disintegration the worn parts of the seal will be compressed as long as the structural frames of both elements stay in shape, which makes the system with a rebate stronger and more durable. Especially in a kinetic system, where higher forces will occur, the circumferential seal might not be easily accessible in its full extent, the compression seal with rebate might be desirable thanks to its resilience.

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[5] Raven, "Product Catalogue 115."

[6] Planet GDZ AG, "Planet Drop-down Seals, Technical Specifications."

On the downside a rebate by definition is a boundary to a moving element and that implies that this option is not feasible in kinetic systems that require different stages of movement.

FIRE PROTECTION DOORS / WINDOWS:

In addition to the neatness and imperviousness a smoke protection door provides, fire protection doors require a system and structure that even in event of temperatures over 1000°C can resist for a given time without deformation or impairment of the neatness of the system. This of course entails a higher level of stiffness of both the frame and the opening, which is usually achieved by separate structural layers, that prevent the deformation and allow for the element to open even after the specific duration of fire resistance they are designed for.

Seal:

The variations of seals and sealing mechanisms as well as their anticipated maintenance and workability in a kinetic system can be assumed identical to the abovementioned sliding seal with contact threshold, drop-down seal and compression seal with rebate of smoke protection openings. Though, while only one intumescent circumferential seal would in theory be sufficient to provide the desired neatness, conventional fire protection doors - especially from higher fire protection classes - tend to have two to three seals at the side and at least one, usually two seals at the bottom side even in case of a flush transition, which again would be advantageous in terms of maintenance in a kinetic system where accessibility might be limited. While the use of intumescent seals might be able to compensate irregularities or smaller damages to the seals, over the process of aging maintenance will become inevitable, very much in favour for the use of rebate seals at the bottom side of the opening.[7]

Structure:

While the whole range of fire protection doors and their different incorporated elements, materials and built-up is endless, we can universalise their complex structure to few components or layers with a certain purpose in the system, almost regardless of the materials a specific system is using.

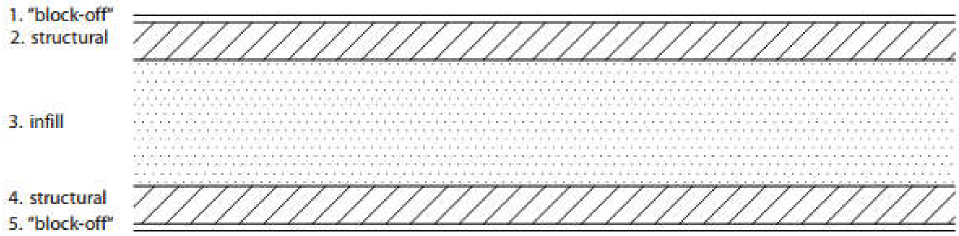

Figure 2: Schematic built up of fire protection systems

An optional "block-off" layer - required only if the structural parts of the system are flammable - on either side of the system functions as a seal for the actual door, an impregnation layer for potentially less fire-resistant inner layers of the opening or frame. Interior to the exterior "block-off" one or several structural layers, that have the capacity of withstanding the heat without

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[7] Safety Section Borough of Merton, "Fire Doors - Technical Guidance."

deforming, are positioned to frame a third inner layer of insulating infill, mostly a high-functioning heat insulation layer.

Abovementioned stability in case of extreme heat seems to be the general core prerequisite for fire protection doors and affirmatively there is a consistent line of the number of structural layers or frames within opening and frame increasing with the increasing fire resistance of the openings.

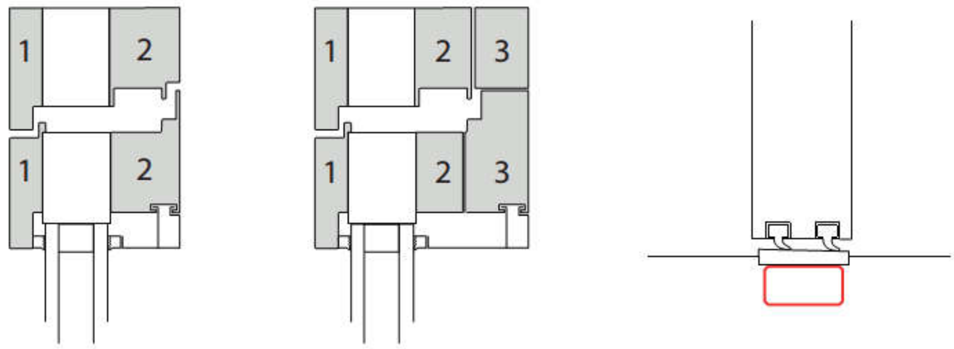

Figure 3: Structural elements increasing in number and strength according to increasing prerequisites for the performance of fire protection systems

Another mean to secure a closer connection between opening and frame and hence better resistance against deformation processes is the increase of direct physical connections and the use of additional rebates: Direct physical connections such as door hinges and connection bolts at the centre of rotation are the most direct and robust connections of opening and frame, but come with a geometric problem for our purposes: They can only connect the frame to the opening in a system based on rotation, but not in a parallel opening, which in a kinetic system would be required.

With every rebate on the other hand even in a kinetic system a structural layer of the frame connects to a structural layer of the opening, which restricts the material to deform into these one or two directions. While some T30-1 doors rely on only one rebate, the use of 2 or 3 rebates is more common and even inevitable for systems of higher fire resistance classes (Figure 3).

Again, in case of a system with flush transition and no bottom rebates and thus no frame that could guarantee stiffness at the bottom of the opening, it is common to implement an additional reinforcing element into the floor, which then ensures the contact threshold to keep its shape. Especially for T60 or T90 door systems the use of three and even more structural elements is very common and thus presumably necessary.

<u>SOUND INSULATION DOORS / WINDOWS:</u>

When it comes to implementing the knowledge we have on sound propagation into the engineering process of a kinetic system, we must put distinguished focus both on sound waves spreading in air and sound vibration spreading within the material.

Airborne sound propagation

As the propagation of sound waves in air can be reduced and converted into vibration by any material or system that interdicts direct airflow, the same logic applied for smoke protection doors can be applied to prevent the dissemination of soundwaves in air. In order to achieve the neatness required to prevent direct air sound propagation from happening, again, the quality and quantity of seals and their behaviour along the process of aging are of importance.

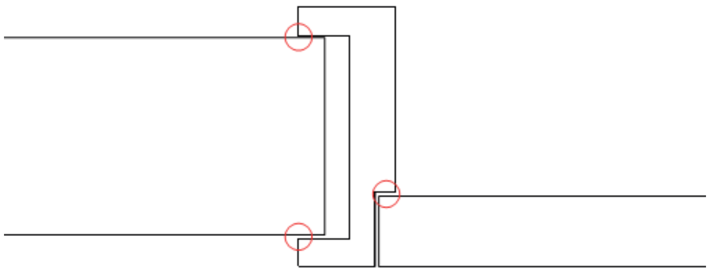

Figure 4: Points of weakness for airborne sound propagation in a door frame

It appears that rather than the opening itself often the connection between frame and wall is responsible for R-values effectively poorer than predicted during laboratory testing, which can generally be attributed to imperfect execution and unpredictability of the exact material properties and quality of the wall at a certain location. It is indispensable whatsoever to cut off any direct air flow between the two spaces, wherefor impermeable seals - prefab or a simple on-site joint - must bridge the gap between frame and wall precautionary on both sides of the opening - as marginal as it might be (Figure 4).[8] While in a conventional setting the forces affecting the frame of an opening - and hence the agitation and deformation of the frame - are minute, in a system where entire building components will move, this will be different and should be considered in the choice of the seals. Other than an on-site silicone line, that is limited in its expansion and once over-stressed will irreparably break loose from frame or wall and, an extruded prefabricated seal leaves more space for reduction and expansion thanks to its malleable build-up.

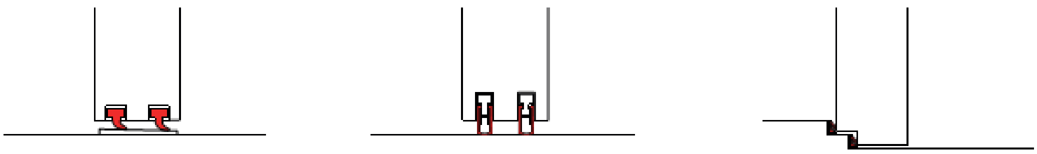

Figure 5: Increasing quantity of seals with increasing prerequisites for the level of performance

For the bottom side of sound insulating openings the sliding seal, the drop-down seal and the seal with a rebate are being used and there is a clear correlation between the performance requirements of the opening and the amount of seals being used, in case of sliding seals and drop-down seals up to two in conventional systems and in case of rebates even more. Again, it should be contemplated, that both the sliding seal and the drop-down seal apart from their

[8] Australian Building Codes Board, “3rd Edition.”

great advantage of not limiting the movement are more susceptible to damages and broken sealing might immediately entail acoustic consequences, which must not happen in a kinetic system combining different users, where loss of feeling of privacy is a primary concern anyway.

Structure-borne sound propagation

When it comes to preventing structure-borne sound propagation in a building component, this can be achieved by choosing a material with higher bulk density, by increasing the thickness of the building component or by creating material or phase changes perpendicular to the direction the sound propagation wants to be avoided.

Increasing the density or the thickness of a component in most cases and especially for a kinetic system is not desirable as it results, if at all feasible, in bulkier, heavier and more expensive elements. On the contrary, the latter allows to increase the R-value in a much more efficient way as every material and phase change reduces the sound transmission significantly.

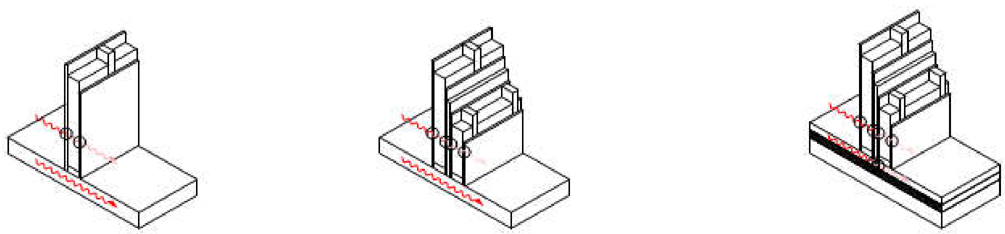

Figure 6: Reduction of structure-borne sound propagation by fragmenting on building scale

Consequently, sound isolating elements commonly consist of various layers of material and air or gas cavities and the connections are sparse and somewhat flexible. In can be generalised that the number of different "layers" increases with increasing performance requirements of the element. While this logic is always applied within the prefabricated systems and presumably also in the larger context of the building, it is very important to follow it during execution and in the context of assembly. After all, would a mistake in execution destroy the whole purpose of implementing a highly efficient sound insulating opening. Hence, these layers of materials and cavities as shown above should never be broken in the direction of sound propagation and if inevitable, as in the case of a window frame, the permeating object has to be of a similar structure of material changes perpendicular to the direction of sound propagation.[9]

A general problem occurs with elements that are placed parallel to the direction of sound propagation such as walls, floor, ceiling and elements permeating a sound insulating building component and directly transmitting vibration from one space to the other. While in conventional constructions this can easily be solved by implementing a cut and change of material, a cavity, in a kinetic system where higher structural strength, smaller building components and reduced weight are required, this must be considered much earlier and already during the design of the structure.[10]

[9] Quirt, "Controlling Air-Borne and Structure-Borne Sound in Buildings."
[10] Quirt.

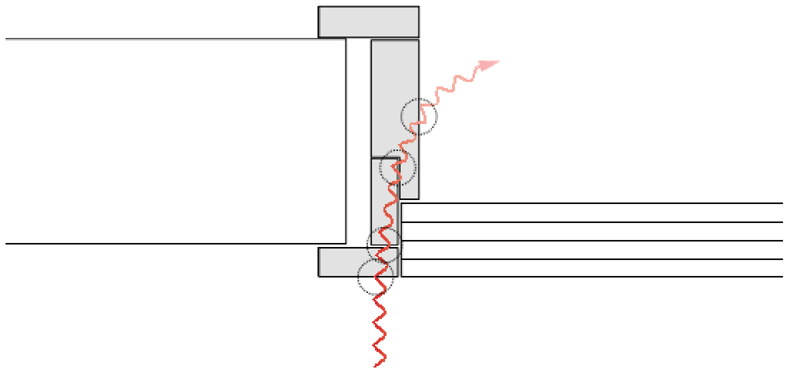

Figure 7: Reduction of structure-borne sound propagation by fragmenting on a component scale

It is important that this logic of creating changes perpendicular to the direction sound propagation wants to be avoided and hence fragmenting the building elements is applied both on a building scale and on a component scale as schematically shown in figure 7. This wrap-around frame permeates the “line of defence” at the joint of two neat systems and creates a direct connection, but thanks to the fragmentation of the frame the vibration is reduced significantly at 4 points of material change. On the downside this fragmentation of elements and preferably little direct material connections between the elements necessary to reduce sound propagation, also weakens the system structurally. That can be disadvantageous in a kinetic system where the closing mechanism of an opening will be subject to much higher forces than in conventional fields of application.

6. CONCLUSION

As the way most fire protection and sound isolation systems are designed is in direct response to the laws of physics, it is not astonishing that their reasoning and logic can be directly applied to a kinetic system and we can even use the performance of existing systems as precedence and proof for an anticipated performance in a kinetic system. Notwithstanding, in a kinetic system more aspects have an effect on a closing mechanism and especially the much higher forces acting in a system of moving elements and the difficulty of accessing the opening mechanisms in case of failure or and maintenance are very problematic.

It can be concluded that the use of both the drop-down and the sliding seal is not advisable owed to accelerated material aging as a result of higher forces working against their structure and built-up and owed to difficulty exchanging the faulty seals after their anticipated failure. Resulting from that we have to know that – at least with conventional seal types and closing mechanisms - a flush transition between spaces will not be possible and accept that a frame will always limit the movement. In other words: more than two resting positions will not be feasible. As the fragmentation of components is necessary for satisfactory sound isolation, the systems are weakened and in order to function in a kinetic system, where much higher forces occur, measures have to be undertaken to ensure sufficient structural performance, which then will probably result in increased material use, extended cross-sections of individual fragments and consequently bulkier closing mechanisms.

Whatsoever, as the options to design a kinetic system are manifold and the applications numerous, a general statement cannot be made. While a bulky closing mechanism might be lethal for one system, there might be more than enough space in another system and while high forces might affect one opening, in another scenario a very small cross-section might be sufficient.

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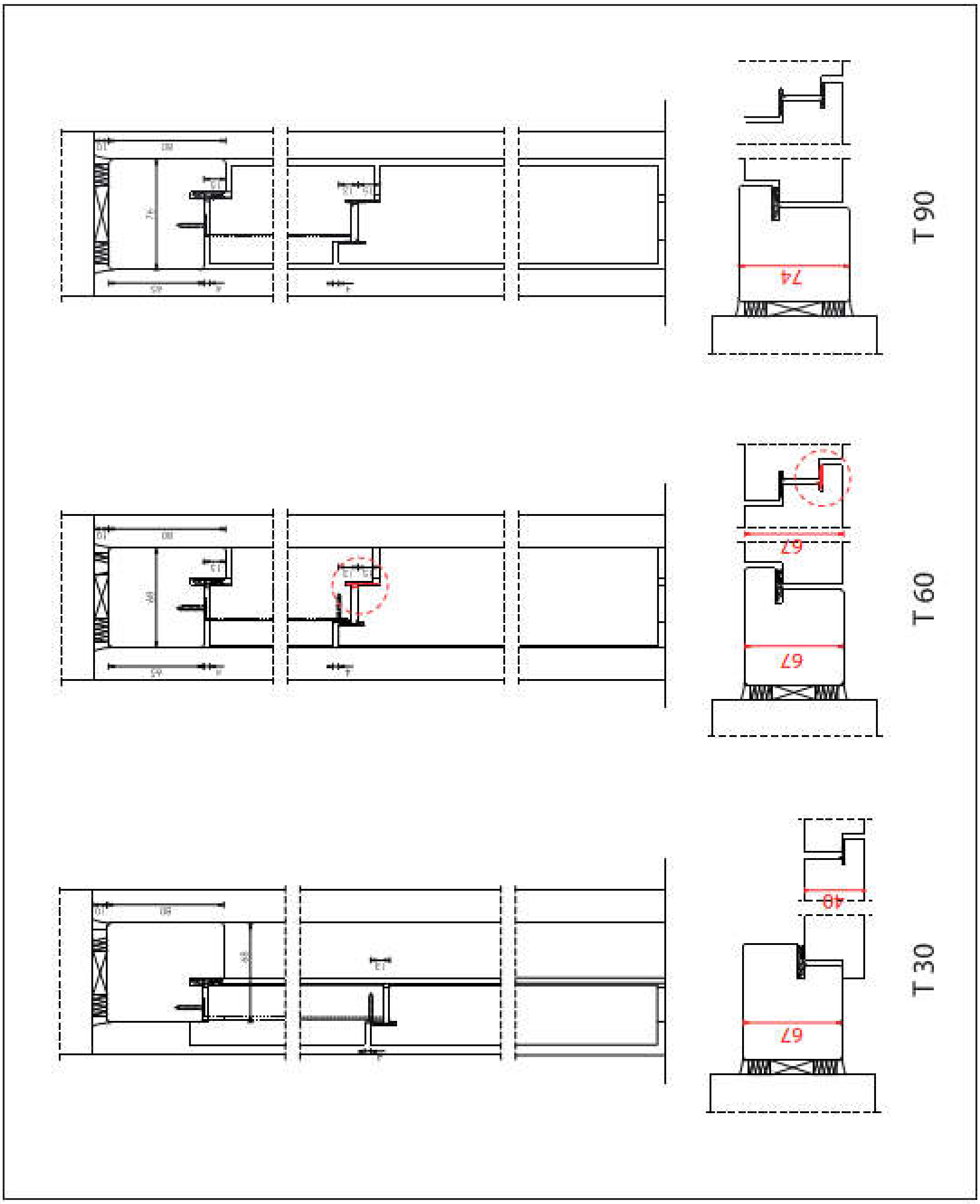
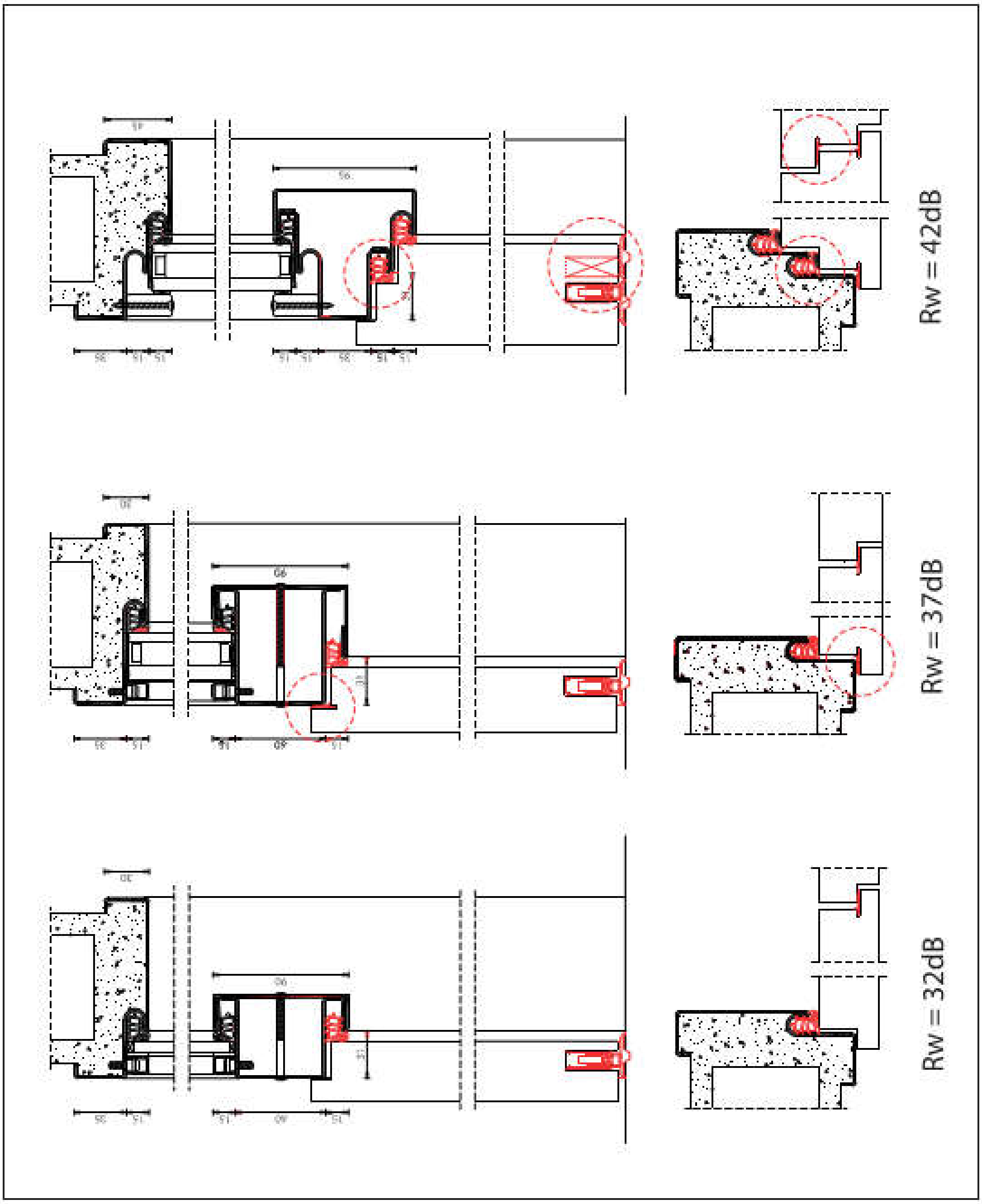
APPENDIX 1:



Exemplary direct comparison of fire protection doors of different levels of performance

Figure altered from Westag & Getalit AG: Type T30(EI30)-2-40-RO-BR, Type T60(EI60)-2-65-RO-BR and Type T90(EI90)-2-65-RO-BR

APPENDIX 2:



Exemplary direct comparison of sound protection doors of different levels of performance

Figure altered from Westag & Getalit AG: Type SK27-2-40-RKG-SZ, Type SK32-2-40-RKG-SZ and Type SK37-2-65-RKG-SZ

APPENDIX 3:

Overview consulted existing systems:

Teckentrup:

T90-1-FSA „Teckentrup 62“, T90-1-FSA „Teckentrup 62“ Außenanwendung, T90-1-FSA „Teckentrup DF“, EI²90-C5-Sa „Teckentrup 62“

https://www.teckentrup.biz/produkte/professional/feuerschutztueren/fuer-den-inneneinsatz/t90-1-fsa-tt-62/, May 2019

Jeld-Wen Door Solutions:

T90:Typ70 W1, Typ70 W2,

Typ70 SK3, Typ48 SK3

https://www.jeld-wen.de/professionals/produkte/tuerloesungen/rauch-und-brandschutztueren/, May 2019

Domoferm:

T90: Premium T90 – 1, Premium T90 – 2

http://www.domoferm.com/produkte/, May 2019

Schüco

Firestop T90/F90 (EI90), various executions

https://docucenter.schueco.com/ , May2019

Westag & Getalit AG:

T90: Typ T90(EI90)-1-65-SZ, Typ T90(EI90)-1-65-BR, Typ T90(EI90)-1-65-RO, Typ T90(EI90)-1-65-RO-SZ, Typ T90(EI90)-1-65-RO-BR, Typ T90(EI90)-2-65, Typ T90(EI90)-2-65-SZ, Typ T90(EI90)-2-65-BR, Typ T90(EI90)-2-65-RO, Typ T90(EI90)-2-65-RO-SZ, Typ T90(EI90)-2-65-RO-BR

T30: Typ T30(EI30)-1-40, Typ T30(EI30)-1-40-SZ, Typ T30(EI30)-1-40-HZ, Typ T30(EI30)-1-40-BR, Typ T30(EI30)-1-40-RO, Typ T30(EI30)-1-40-RO-SZ, Typ T30(EI30)-1-40-RO-HZ, Typ T30(EI30)-1-40-RO-BR, Typ T30(EI30)-1-40-RKG, Typ T30(EI30)-1-40-RKG-SZ, Typ T30(EI30)-1-40-RKG-BR, Typ T30(EI30)-2-40, Typ T30(EI30)-2-40-SZ, Typ T30(EI30)-2-40-HZ, Typ T30(EI30)-2-40-BR, Typ T30(EI30)-2-40-RO, Typ T30(EI30)-2-40-RO-SZ, Typ T30(EI30)-2-40-RO-HZ,

SK27: Typ SK27-1-40-HZ, Typ SK27-1-40-SZ, Typ SK27-1-40-BR, Typ SK27-1-40-RO-SZ, Typ SK27-1-40-RO-HZ, Typ SK27-1-40-RO-BR, Typ SK27-1-40-RKG-SZ, Typ SK27-1-40-RKG-HZ, Typ SK27-1-40-RKG-BR, Typ SK27-2-40-SZ, Typ SK27-2-40-HZ, Typ SK27-2-40-BR, Typ SK27-2-40-RO-SZ, Typ SK27-2-40-RO-HZ, Typ SK27-2-40-RO-BR, Typ SK27-2-40-RKG-SZ, Typ SK27-2-40-RKG-HZ, Typ SK27-2-40-RKG-BR

SK 32: Typ SK32-1-40-SZ, Typ SK32-1-40-HZ, Typ SK32-1-40-BR, Typ SK32-1-40-RO-SZ, Typ SK32-1-40-RO-HZ, Typ SK32-1-40-RO-BR, Typ SK32-1-40-RKG-SZ, Typ SK32-1-40-RKG-BR, Typ SK32-2-40-SZ, Typ SK32-2-40-HZ, Typ SK32-2-40-BR, Typ SK32-2-40-RO-SZ, Typ SK32-2-40-RKG-SZ, Typ SK32-2-40-RKG-BR

SK 37: Typ SK37-1-43-SZ, Typ SK37-1-43-HZ, Typ SK37-1-43-BR, Typ SK37-1-43-RO-SZ, Typ SK37-1-43-RO-HZ, Typ SK37-1-43-RO-BR, Typ SK37-1-43-RKG-SZ, Typ SK37-1-43-RKG-BR, Typ SK37-2-43-SZ, Typ SK37-2-43-HZ, Typ SK37-2-43-RKG-SZ, Typ SK37-2-43-RKG-BR, Typ SK37-1-65-SZ, Typ SK37-1-65-HZ, Typ SK37-1-65-BR, Typ SK37-1-65-RO-SZ, Typ SK37-1-65-RO-HZ, Typ SK37-1-65-RO-BR, Typ SK37-1-65-RKG-SZ, Typ SK37-2-65-SZ, Typ SK37-2-65-HZ, Typ SK37-2-65-BR, Typ SK37-2-65-RO-SZ

SK42: Typ SK42-1-71-SZ, Typ SK42-1-71-HZ

https://www.westag-getalit.com/, May 2019

Hörmann:

T30: HE311, HE321, HE331, HL310 S, HL 320 S, ASW / ASV

T60: HE611, HE621, HE631, HE611, HE631

T90: HE911, HE921, HE931, HE911, HE931, HL910 H, HL930 H

S: Typ RS 55, Typ HS 75, Typ H 16 S, RS 100, RS 200 / RS 300, AS30/FR

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