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Impact sound insulation of wooden joist constructions: Collection of laboratory measurements and trend analysis

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Abstract

Wooden building systems are becoming more common. Still, there are a huge variety of floor assemblies in the market. The floor assemblies normally become the weakest part due to impact load from walking persons. So far, there are no reliable standardized calculation models available regarding prediction of impact sound in the entire frequency range. Therefore, the design is always based upon previous experiences and available measurements. For the development of prediction models, the first approach is to carry out a grouping of various available floor assemblies. From that, the aim is to trace similarities and carry out simplifications. Correlation is found between the single number $L'_{nT,w} + C_{I,50\text{-}2500}$ and the mass per unit area. It is also found that the ceiling system is useful in order to optimize the construction. The data will be further processed and used in the model development and to propose optimization of wooden floor assemblies.

Keywords

Lightweight, timber, impact sound insulation, building acoustics, floor

Introduction

Lightweight building technique

In traditional lightweight buildings, walls and floors are rigidly connected, but the ceiling is often elastically connected to the beams and sometimes completely separated. Regarding the upper floor construction, a more or less resilient solution is common but actually depending on the requirement level in each country. When concentrating on the floor construction itself and laboratory

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measurements, the effect of supporting walls and flanking transmission is not included. The effect of these contributions is therefore outside of this study. The majority of a timber floor construction is so far typically erected on site under different conditions and workmanship. It is difficult to document the consequence of this with respect to the sound insulation, but it will probably increase the spreading of the properties as shown by Johansson[1] and Ljunggren and Ågren.[2] When considering research and studies from some years ago and from different countries, a lot of laboratory measurement results are actually available. It includes some comprehensive parametric studies performed on specific timber floor constructions, see for instance Warnock and Birta,[3] Sipari et al.,[4] Fothergil and Royle[5] and Johansson,[6] besides measurements from unpublished projects.

Sound insulation requirements

The building code in many countries was developed when lightweight structures were rarely used or not even permitted for multi-storey residential buildings. Thus, requirements are adapted to heavyweight structural behaviour, that is, current single number ratings presuppose structures which actually have very good low-frequency sound insulation and are not sensitive to perceived vibrations, at least not to vibrations from normal private activities. Lightweight structures often exhibit poor low frequency behaviour, and if using a single number rating without spectrum adaptation term as shown in EN-ISO 717-2:1996,[7] there is no consideration at all for frequencies below 100 Hz. A few countries have extended the sound insulation requirements or recommendations using the ISO (International Organization for Standardization) spectrum adaptation terms from 50 Hz. New lightweight building techniques are growing, and so more countries need to incorporate this either formally or by recommendations, at least for residential buildings. Table 1 shows impact sound insulation requirements and recommendations given in different countries participating in this project.

Objective

This article presents results from numerous well-controlled sound insulation measurements performed in laboratory. As the impact sound insulation tends to be the most significant problem for the wooden floor construction building technique,[8,9] such measurements are in focus. The main objective is to highlight some specific phenomena, in order to see in what way structural differences related to the grouping of the constructions affect the sound insulation properties. An objective is also to deliver well-controlled and systematically performed experimental results that can

Table 1. Impact sound insulation requirements and recommendation/certification.

Country	Impact sound insulation	
	Legal requirement	Recommendation/certification
Austria	$L'_{nT,w} \leqslant 48$dB	–
France	$L'_{nT,w} \leqslant 58$dB	$L'_{nT,w} \leqslant 55$dB
Germany	$L'_{n,w} \leqslant 53$dB	$L'_{n,w} \leqslant 46$dB
Norway	$L'_{n,w} \leqslant 53$dB	$L'_{n,w} + C_{I,50\text{–}2500} \leqslant 53$dB
Sweden	$L'_{nT,w} \leqslant 56$dB and $L'_{nT,w} + C_{I,50\text{–}2500} \leqslant 56$dB	–
Switzerland[a]	$L'_{n,w} \leqslant 50$dB	$L'_{n,w} \leqslant 45$dB

[a]Intermediate values.

verify solutions and give input for better prediction tools for lightweight floor constructions. To this end, results included in this article are first presented by country since floor construction is specific to each country: typical construction will depend on regulation requirements and local expertise. However, it will be seen that floor configuration grouping is possible across the European countries considered.

Floor assemblies

Introduction

In the following section, typical timber floor assemblies for residential buildings will be presented The information will be given for each contributing country in alphabetic order. The data collection presented in this article concentrates mainly on typical national solutions, but divided into different groups depending on structural differences. The grouping of constructions has been based on work in the Silent Timber Build (STB) project (see Homb[10]). Floor assemblies presented in this article are the following main types according to these grouping:

- *Construction group A*: wooden joist constructions;
- *Construction group B*: hybrid wooden joist constructions with gravel or concrete.

From the different countries, quite different solutions are found but also in some cases there are identical constructions when considering the principal solutions given by the grouping of the constructions. Due to traditions, it is not surprising that many of the same solutions in Sweden and Norway are found; however, also in France, similar floor assemblies are detected. Also due to traditions, Switzerland and Germany are often using a combination of concrete and wood. Therefore, such solutions dominate the findings when we collect laboratory measurement data from these countries. Even if France has some floor assemblies similar to Scandinavia, they are also using a combination of concrete on various wooden joist solutions.

France

In France, wooden joist constructions have not been that common in modern residential buildings, and therefore, common solutions have been based on a stiff top floor solution of chipboards, that is, group A constructions or even concrete with soft floor coverings on top, that is, group B constructions. In order to fulfil French regulation for residential buildings, separating floors are mounted with a resilient top floor (composed generally of mineral wool as resilient layer and of either boards or cast-in-place screed). Common for these solutions is a ceiling solution based on steel suspension products, often non-spring types but also resilient systems. The first mentioned solution is in the following coded as FS-CS solutions (corresponding to Floor Stiff–Ceiling Stiff meaning stiff top floor and stiff suspended ceiling) and the second one as FS-CR (Floor Stiff–Ceiling Resilient meaning stiff top floor and resilient suspended ceiling). The ceiling commonly incorporates a layer of mineral wool. A principal drawing of this construction type is presented in Figure 1(a). From both construction groups, there also exist laboratory measurement results with no coupling between the joist construction and the ceiling construction (independent double frame for the floor and ceiling), that is, solutions with the code FS-CN (Floor Stiff–Ceiling No coupling) similar to that commonly found in Swedish and Norwegian solutions. A principal drawing is presented in Figure 1(b).

Hybrid floors with an important concrete layer, falling into group B constructions, are not so much used yet for apartment buildings in France.

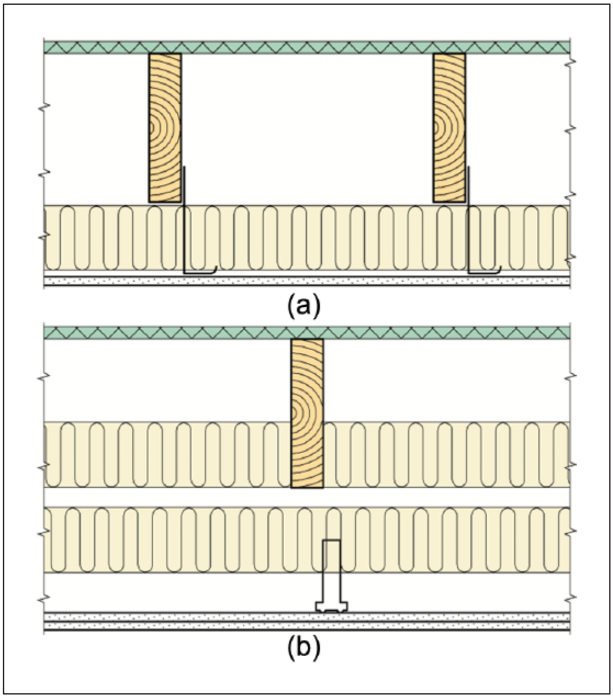


Figure 1. Common types of French wooden joist constructions: (a) type A, FS-CS and (b) type A, FS-CN.

Germany

In Germany, timber floor constructions are rarely used. But it is an increasing interest and examples and documentation exist based on solutions developed in Austria and Switzerland. Due to traditions and requirement level, these solutions normally have been based on a hybrid Timber-concrete composite floor solution (tccf) with concrete layer on the sub-floor (plywood/osb panel), that is, construction type B, FR-CS (Floor Resilient–Ceiling Stiff), with either prefabricated concrete elements which are directly laid on the floor joist members or more common as concrete on top of the subfloor. The ceiling can either consist of plasterboard on rigidly fixed laths or of a suspended ceiling on resilient hangers. In the following, these solutions are encoded as hybrid FR-CS or hybrid FR-CR (Floor Resilient–Ceiling Resilient) solutions (concrete with a resilient top floor and resilient suspended ceiling). Principal drawings of these floor assemblies are presented in Figure 2(a) and (b).

Norway

In Norway, three main wooden joist constructions have been common in the last 10–20 years. The major choice has been using solutions based on resilient profiles in the ceiling and a resilient top floor solution. Different types of steel springs or resilient steel channels have been mounted underneath the timber beams. At the floor, floating floor on mineral wool products with a certain limit of dynamic stiffness has been the most common. Similar to the Swedish solution, these are encoded as FR-CR solutions (resilient floor and resilient ceiling). A principal drawing of this construction type is presented in Figure 3(a). Previously, it has also been very common to build similar floors without a resilient layer at the floor, coded as FS-CR solutions.

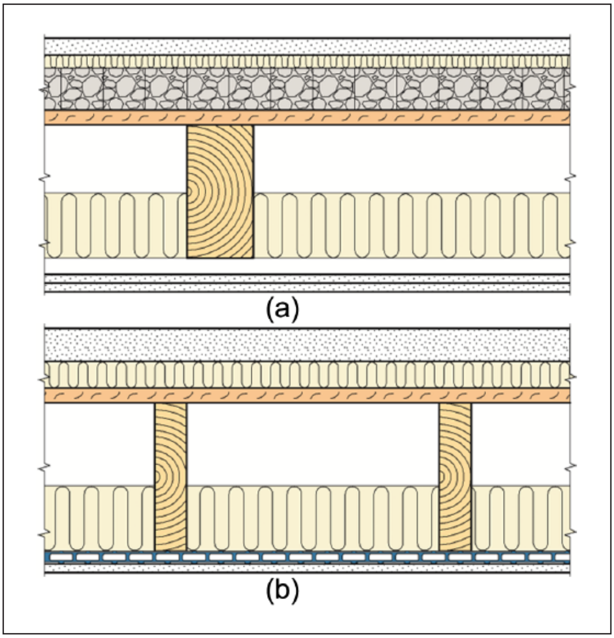


Figure 2. Common types of German wooden joist constructions: (a) type B, FR-CS and (b) type B, FR-CR.

The third solution with increased market share in the last 5 years has been prefabricated three-dimensional (3D) module-based solutions (usually referring to factory-built modules transported to the site and stacked to create a multi-family building). This construction type implies separate independent wood beams system for the floor from the upper module and for the ceiling from the lower module. This solution is similar to the Swedish one presented below, coded as FS-CN solutions (no coupling between joists and ceiling construction). In these solutions, it has not been common to use floating floors on mineral wool products nor use resilient profiles for mounting the ceiling. Different from many Swedish module-based buildings, it has not been common to use vibration insulation products between peripheral frames of superposed modules in Norway. A principal drawing of this construction type is presented in Figure 3(b).

Sweden

In Sweden, three main wooden joist constructions have been common in the last 5–10 years. The most common type has been a solution based on resilient profiles in the ceiling and more or less resilient top floor solutions. Relatively stiff underlayer in the top floor was applied sometimes, but very often floating floors on mineral wool products with a certain upper limit of dynamic stiffness have been used. In the following, these are coded as FR-CR solutions (resilient floor and resilient ceiling). This solution is more or less identical with construction type presented in Figure 3(a).

As mentioned previously, another solution with rapidly increased market share has been prefabricated 3D module-based solutions, briefly presented in section ‘Norway’. For such solutions, floating floor on mineral wool products is rarely used and not resilient profiles below the ceiling beams. But due to flanking transmission from the lightweight load-bearing walls, it has been more and more common to use vibration insulation products between peripheral frames of superposed

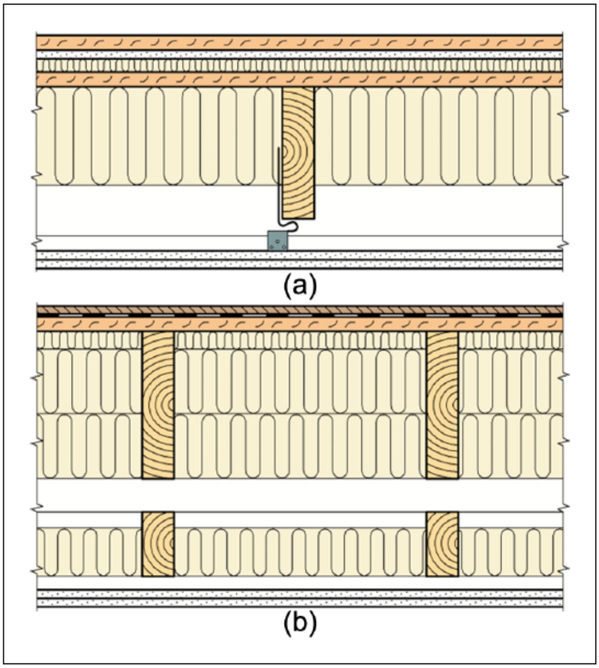


Figure 3. Common types of Norwegian wooden joist constructions: (a) type A, FR-CR and (b) type A, FR-CN.

modules, either point elastic solutions or line elastic solutions. Presentation of these solutions with measurement results and limitation is presented by Ljunggren and Ågren.[2] But due to the concept of complete 3D solutions, it is not possible to find laboratory measurements with the separate constructions itself. In the following, we assign the codes FS-CN or FR-CN (Floor Resilient–Ceiling No coupling) for those solutions (no coupling between beams and ceiling construction). This solution is more or less identical with construction type presented in Figure 3(b).

The third and also upcoming solution in Sweden is based on a hybrid solution with cross-laminated timber (CLT) elements on beams. The most successful solution has been developed by Martinsons of which a lot of in situ measurement results exist as well as some laboratory measurements. In fact, the complete solution for residential buildings is based on separate beams for the ceiling. Due to a combination with CLT elements in the load-bearing walls, it has also been necessary to use elastic interlayers between the floor element and the lower load-bearing wall. In the following, this floor assembly is also coded as a hybrid FS-CN solution (no coupling between joist and ceiling construction). A principal drawing of this construction type is presented in Figure 4.

Impact sound insulation properties

Measurement method and data

The impact sound insulation measurements were carried out according to ISO 140-6, versions valid at the time of measurements. Major part of measurements after 1995 has been carried out in the frequency range from 50 Hz. The measured normalized impact sound pressure levels in the frequency range 50–5000 Hz (or 100–3150 Hz) are presented as graphs in the following sections.

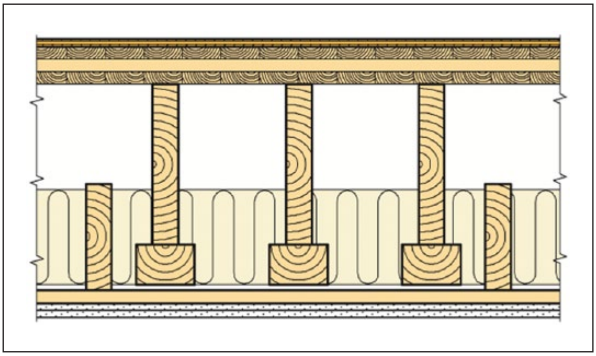


Figure 4. Common type of Swedish wooden joist constructions: type A, hybrid CLT and wooden joist construction, FS-CN.

From the test result, different single number quantities for rating the impact sound insulation were calculated, that is, $L_{n,w}$, the spectrum adaptation term, $C_{I,50\text{-}2500}$ and the sum of these, $L_{n,w}+C_{I,50\text{-}2500}$; see EN-ISO 717-2:1996.[7]

In the following sections, measurement results compiling comparable laboratory measurement data from the different countries are presented. Totally, approximately 170 laboratory measurement data have been collected and evaluated. However, for each construction group, a limited number of records will be reported. The idea has been to extract results only from the most comparable solutions. In section ‘Construction group A: wooden joist constructions’, impact sound insulation data from solution type A, measured in Germany, Finland, France, Norway, Sweden and Switzerland, are presented. In section ‘Construction group B: wooden joist constructions with gravel or concrete’, impact sound insulation results from solution type B, measured in France, Norway, Germany and Switzerland, are presented. For all presented data, the total mass per unit area (kg/m^2, denoted mpua) of the floor construction is given.

Through the analysis of this measurement results compilation, it is expected to observe and deduce what effect has the most influence on the floor performance in terms of impact noise. Indeed, it could be expected that mpua, ceiling mounting type and floor covering system are of importance.

Construction group A: wooden joist constructions

Laboratory measurement results of wooden floor constructions with stiff top floor and stiff suspended ceiling are presented in Figure 5. Even if the material specification may vary, it is an impressive correlation between measurements from Germany and Norway. The French measurement deviates with more than 10 dB, but this solution cannot be considered as fully comparable to the other two. The reason for this is the mounting of the ceiling (stiff suspended but) based on steel furring channels attached to steel hangers connected to the joists (rather than wood battens for the German and Norwegian systems). This mounting obviously introduced some flexibility between the joist and the ceiling. Such solutions will of course reduce the sound radiated from the ceiling. The measurement curve therefore verifies the effect of this more flexible ceiling suspension, with result similar to solutions with resilient steel profiles as presented in Figures 6 and 7.

Laboratory measurement results of floor constructions with stiff top floor and resilient suspended ceiling are presented in Figure 6. In Figure 6(a), results are given for solutions with mpua

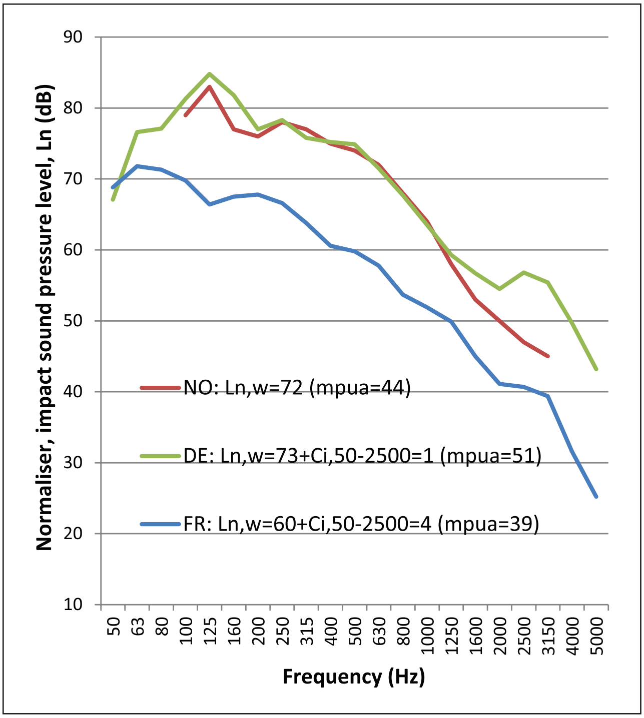


Figure 5. Measurement results from construction type A, FS-CS NO,[11] DE[12] and FR.[13]

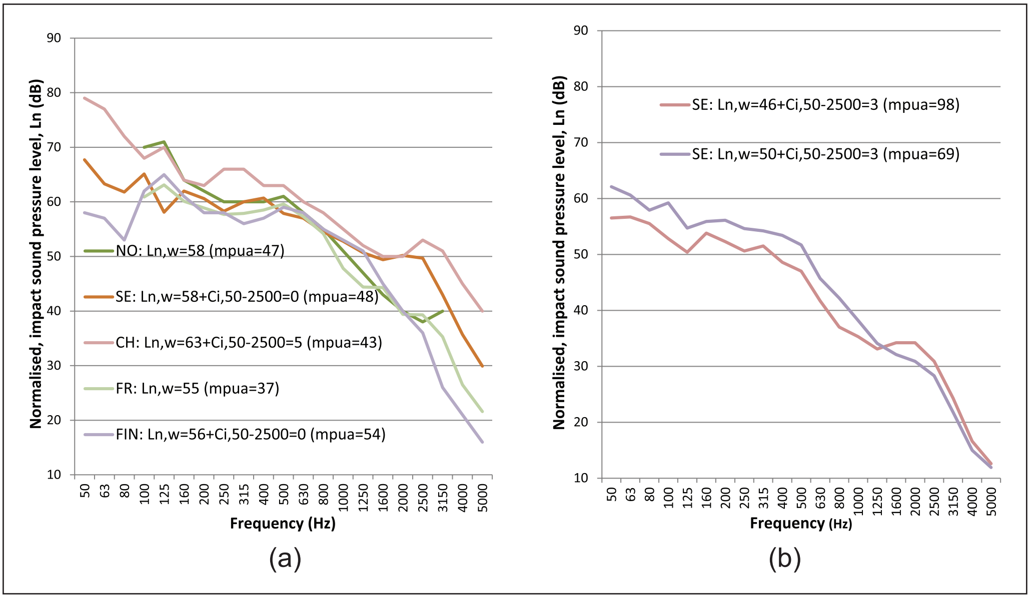


Figure 6. Measurement results from construction type A, FS-CR: (a) NO from Homb et al.,[14] SE from Nilsson,[15] CH from Lignum,[16] FR from Bois-AcouTherm[17] and FIN from Sipari et al.,[4] and (b) 2 × SE from Nilsson.[15]

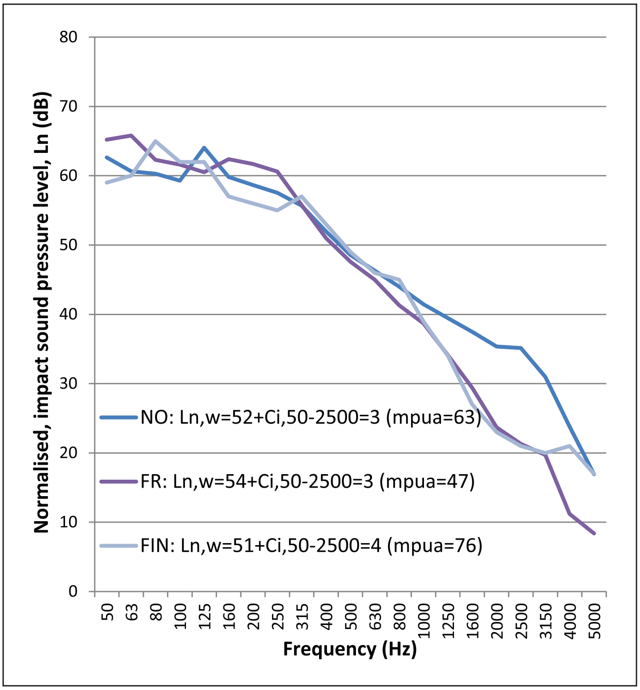


Figure 7. Measurement results from construction type A, FS-CN NO from Homb,[18] FR from Acoubois[13] and FIN from Sipari et al.[4]

of below approximately 50 kg/m². The results deviate considerably in the frequency range below approximately 160 Hz and above 1600 Hz. The deviation in the high-frequency range is not important in this article because it depends very much on the softness of the floor covering and the fact that the impact sound insulation anyway is good in this frequency range. The deviation in the low-frequency range needs to be investigated due to a significant increase (more than 2–3 dB) of the $L_n+C_{I,50\text{-}2500}$ value. A hypothesis is an effect of the joist and floor stiffness and modal behaviour. In the middle part of the frequency range, the result seems to correlate well with the mpua. This effect is also clearly shown in Figure 6(b).

Laboratory measurement results of floor constructions with stiff top floor and a fully independent ceiling uncoupled from the load-bearing joist construction are presented in Figure 7. The results show a relatively good correlation between the different measurements in the whole frequency range below approximately 1250 Hz. The deviation in the low-frequency range seems to correlate with the mpua. Different softness of the floor covering probably explains the deviations in the high-frequency range.

Laboratory measurement results of floor constructions with floating screed on resilient layer and a stiff suspended ceiling are presented in Figure 8. The results show deviation of 5–10 dB between the curves in the most important frequency range below 400 Hz even if the mpua is comparable. It is obvious that the properties of the resilient layer are of importance, but another reason could be related to the ceiling solution details and sound radiation from the ceiling. It probably explains huge deviations observed in the high-frequency range, but this is normally of minor importance with respect to the single number quantity.

Laboratory measurement results of floor constructions with floating screed on resilient layer and resilient suspended ceiling are presented in Figure 9. The results show deviation of

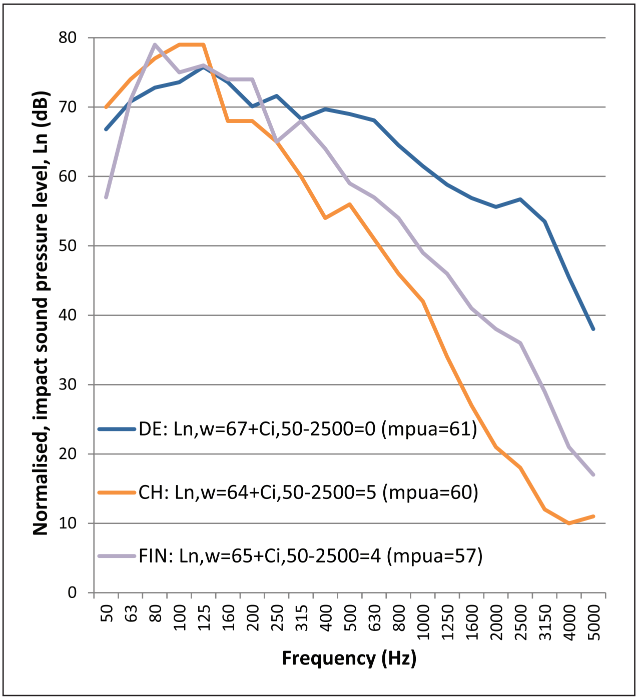


Figure 8. Measurement results from construction type A, FR-CS DE from Späh et al.,[12] CH from Lignum[16] and FIN from Sipari et al.[4]

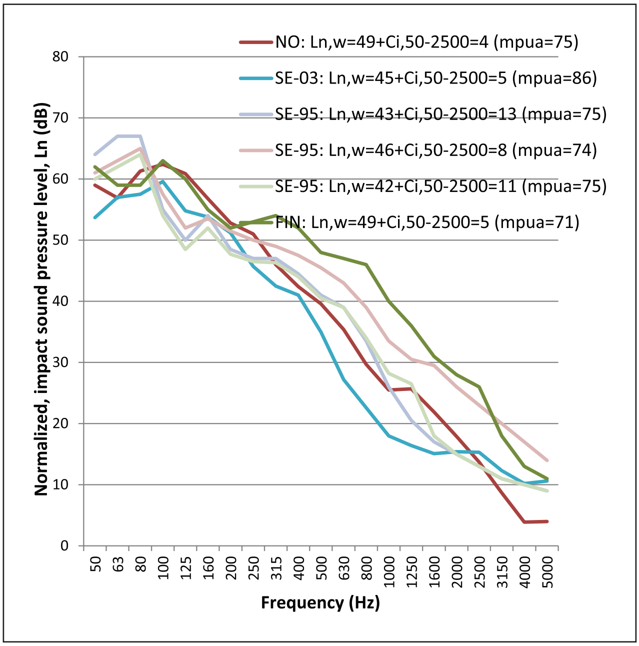


Figure 9. Measurement results from construction type A, FR-CR NO from Nemko,[19] SE-03 from Nilsson,[15] 3 × SE-95 from Johansson[6] and FIN from Sipari et al.[4]

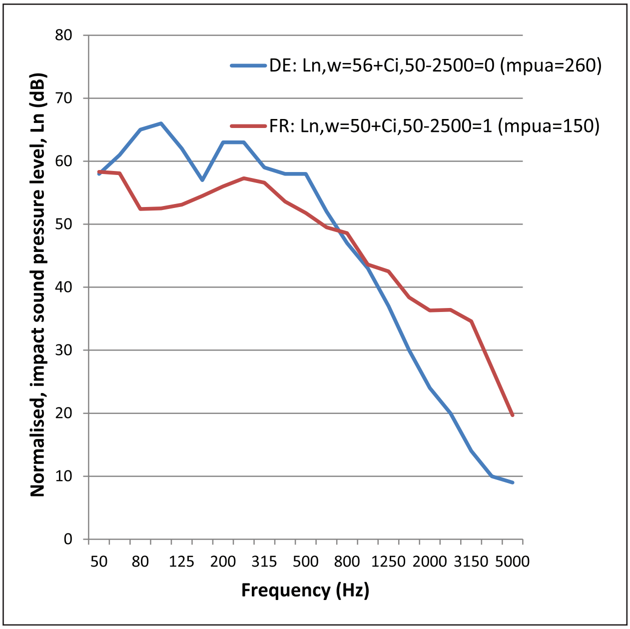


Figure 10. Measurement results from construction type B, FS-CS DE from Lignum[16] and FR from Acoubois.[13]

approximately 10 dB between the curves in the whole frequency range below 400 Hz, but with respect to single number quantities, the maximum difference of $L_{n,w}+C_{I,50\text{-}2500}$ is 6 dB. The results partly correlate with the mpua, as shown by curve SE-03 with the highest mpua and lowest single number quantity. With increasing number of layers, resilient products and possible combination of sheet layers, it is not surprising that such spreading will occur. But it is important to investigate the deviations between the different solutions in the low-frequency range, due to the necessity to limit the sound pressure level in the low-frequency range and to optimize solutions. Such investigations should at least include the joist and floor stiffness in combination with the effect of resilient top floor behaviour.

Construction group B: wooden joist constructions with gravel or concrete

Laboratory measurement results of wooden floor constructions with stiff top floor, added mass and a ceiling on rigidly fixed laths or stiff steel hangers are presented in Figure 10. In the frequency range below 800 Hz, the deviation between the curves appears to be relatively high because of the steel hangers and increased cavity depth of the FR case from Acoubois.[13] The results therefore show apparently a negative effect of the relatively high mpua of the DE case, from Lignum.[16] As mentioned before, the sound pressure level is sensitive to connections and radiated sound from the stiff suspended ceiling.

Laboratory measurement results of floor constructions with stiff top floor, added mass and a ceiling decoupled from the load-bearing joist construction are presented in Figure 11. The results exhibit low impact sound pressure level except in the frequency range below 100 Hz. Further studies should be focused on prediction of the impact sound insulation when adding alternative masses to these wooden floors.

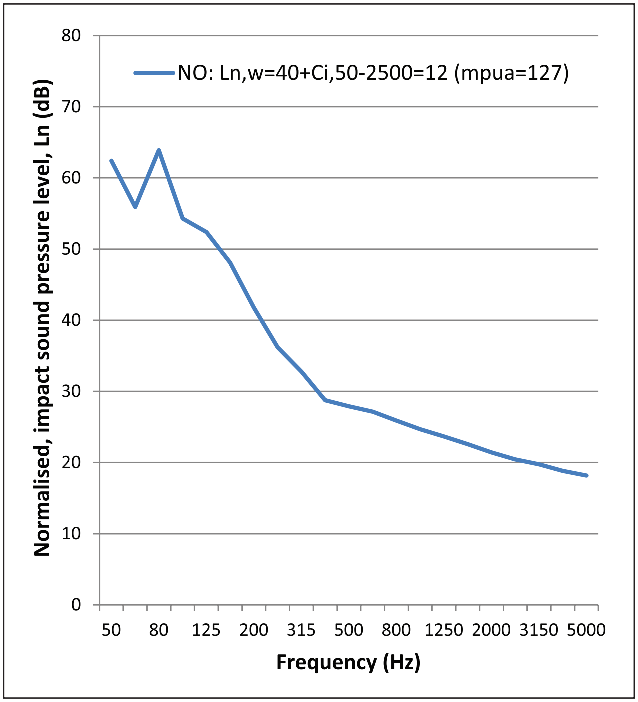
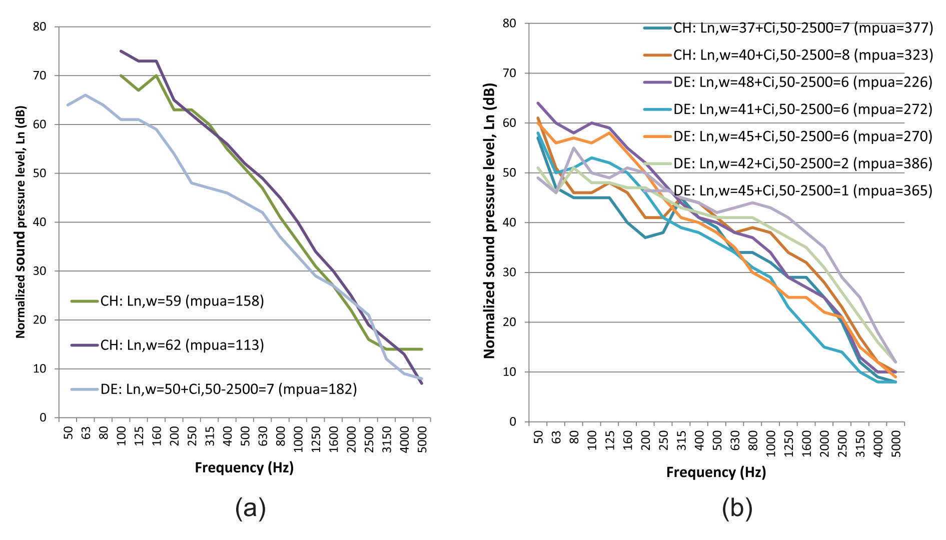


Figure 11. Measurement results from construction type B, FS-CN NO from Homb[18] and FR from Acoubois.[13]

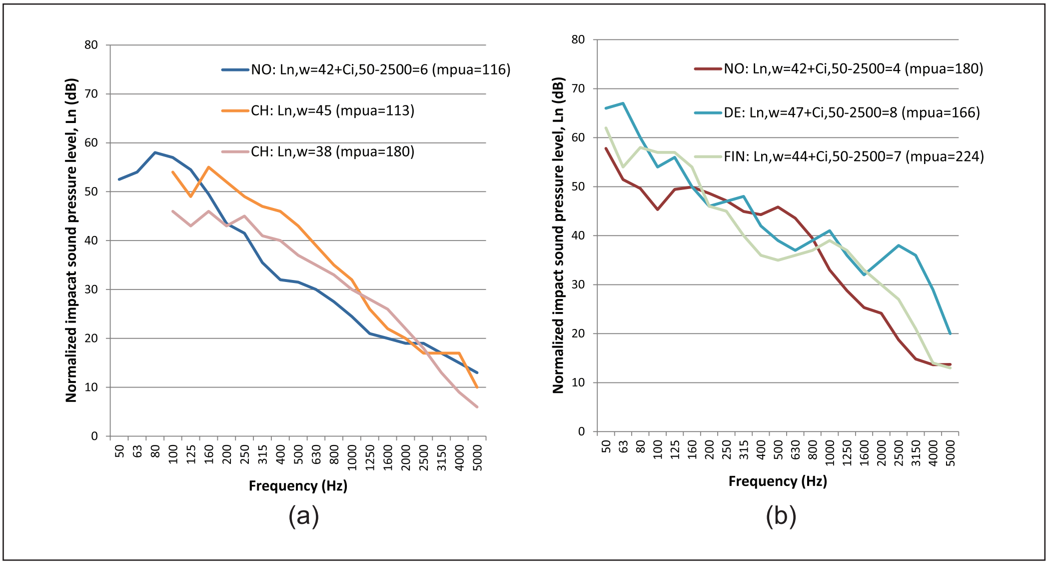
Laboratory measurement results of floor constructions with a resilient top floor and a ceiling on rigidly fixed laths are presented in Figure 12. The results presented in Figure 12(a) (mpua < 200 kg/m^2) show deviation of approximately 5–15 dB in the frequency range below 800 Hz. Some part of this deviation is explained by differences of the mpua. Similar to other objects with stiff suspended ceiling, connections and sound radiation from the ceiling may be an important reason for differences between these measurement curves. The results presented in Figure 12(b) (mpua > 200 kg/m^2) show deviation of approximately 5–20 dB in the frequency range below 630 Hz. But looking into the single number quantity, $L_{n,w} + C_{I,50\text{-}2500}$, a strong correlation between the mpua and single number quantity is achieved. For these heavy solutions with use of gravel to increase the mass, variations due to the ceiling solution seem to be, in this case, of minor importance.

Laboratory measurement results of floor constructions with a resilient top floor and a suspended ceiling on resilient hangers are presented in Figure 13. In the middle frequency range, there are significant differences between the NO result from IGP[20] and CH results from Lignum[16] (see Figure 13(a)). A possible explanation is the position of the gravel. The gravel is at a sub-board for the NO case and above chipboard on the wooden beams for the CH cases. The deviation between the two CH cases correlates well with the differences of the mpua in the low-frequency range. The results presented in Figure 13(b) show a total spreading of 9 dB with respect to the $L_{n,w} + C_{I,50\text{-}2500}$, but these variations do not correlate with the mpua levels. The deviation occurs at frequencies below approximately 200 Hz, but it is difficult to point out a reliable explanation of these results. In the NO case from Homb,[21] concrete tiles have been installed on a relatively stiff resilient layer, while the concrete in the DE case from Lignum[16]



(a) (b)

Figure 12. Measurement results from construction type B, FR-CS: (a) 2 × CH from Lignum[16] and DE from Lignum,[16] and (b) 2 × CH from Lignum[16] and 5 × DE from Lignum.[16]



(a) (b)

Figure 13. Measurement results from construction type B, FR-CR: (a) NO from IGP[20] and 2 × CH from Lignum,[16] and (b) NO from Homb,[21] DE from Lignum[16] and FIN from Sipari et al.[4]

has been installed on a soft resilient layer. In the DE case, a sharper peak level at the resonance frequency of the system can be expected compared to the NO case. In the FIN case from Sipari et al.,[4] a relatively thin resilient layer may explain poor results in the low-frequency range compared to the high mpua.

Table 2. Main results, impact sound insulation from construction type A.

Type A	$L_{n,w}$ (dB)	$C_{I,50\text{-}2500}$ (dB)	Sum (dB)	Mass per unit area (kg/m^2)	Source
FS-CS	60	4	64	39	FR
FS-CS	72	–	–	44	NO
FS-CS	73	1	74	51	DE
FR-CS	65	4	69	57	FIN
FR-CS	64	5	69	60	CH
FR-CS	67	0	67	61	DE
FS-CR	55	–	–	37	FR
FS-CR	63	5	68	43	CH
FS-CR	58	–	–	47	NO
FS-CR	58	0	58	48	SE
FS-CR	56	0	56	54	FIN
FS-CR	50	3	53	69	SE
FS-CR	46	3	49	98	SE
FR-CR	49	5	54	71	FIN
FR-CR	46	8	54	74	SE
FR-CR	43	13	56	75	SE
FR-CR	49	4	53	75	NO
FR-CR	42	11	53	75	SE
FR-CR	45	5	50	86	SE
FS-CN	54	3	57	47	FR
FS-CN	52	3	55	63	NO
FS-CN	51	4	55	76	FIN

FS-CS: Floor Stiff–Ceiling Stiff; FR-CS: Floor Resilient–Ceiling Stiff; FS-CR: Floor Stiff–Ceiling Resilient; FR-CR: Floor Resilient–Ceiling Resilient; FS-CN: Floor Stiff–Ceiling No coupling.

Result evaluation

Main results

In the following, the main results from previous sections are given. Table 2 shows single number values and corresponding mpua of construction type A. Figure 14 shows the $L_{n,w}+C_{I,50\text{-}2500}$ values as a function of the mpua for solutions with resilient ceiling or separate ceiling. The figure also includes a curve based on a ratio between the $L_{n,w}+C_{I,50\text{-}2500}$ values and the mpua of −30 log (mpua). The −30 log term refers to the basic equation of impact sound insulation of homogeneous floors.

Table 3 shows single number values and corresponding mpua of construction type B. Figure 15 shows the $L_{n,w}+C_{I,50\text{-}2500}$ values as a function of the mpua for solutions with resilient top floor. The figure also includes a curve based on a ratio between the $L_{n,w}+C_{I,50\text{-}2500}$ values and the mpua of −40 log (mpua). The −40 log term refers to the basic equation of impact sound insulation of homogeneous floors including the effect of a resilient sub-floor.

Result evaluations

Comparing laboratory measurements for similar floor assemblies, sometimes the frequency domain results coincide rather well and sometimes they coincide rather poorly. Table 4 shows an overview of similarities in the frequency domain when influences of the mpua are taken into account.

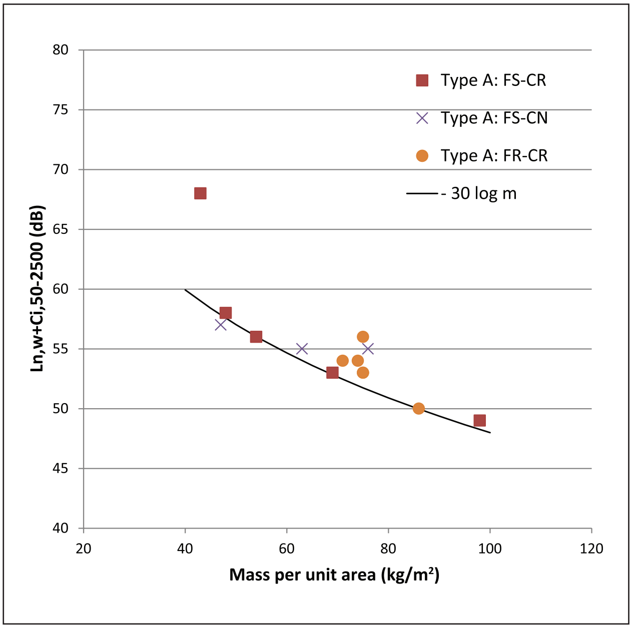


Figure 14. Single number values as a function of mass per unit area, construction type A.

Table 3. Main results, impact sound insulation from construction type B.

Type B	$L_{n,w}$ (dB)	$C_{I,50\text{-}2500}$ (dB)	Sum	Mass per unit area (kg/m^2)	Source
FS-CS	50	1	51	150	FR
FS-CS	56	0	56	260	DE
FR-CS	62	–	–	113	CH
FR-CS	59	–	–	158	CH
FR-CS	50	7	57	182	DE
FR-CS	48	6	54	226	DE
FR-CS	45	6	51	270	DE
FR-CS	41	6	47	272	DE
FR-CS	40	8	48	323	CH
FR-CS	45	1	46	365	DE
FR-CS	37	7	44	377	CH
FR-CS	42	2	44	386	DE
FR-CR	45	–	–	113	CH
FR-CR	42	6	48	116	NO
FR-CR	47	8	55	166	DE
FR-CR	42	4	46	180	NO
FR-CR	38	–	–	180	CH
FR-CR	44	7	51	224	FIN
FS-CN	40	12	52	127	NO

FS-CS: Floor Stiff–Ceiling Stiff; FR-CS: Floor Resilient–Ceiling Stiff; FR-CR: Floor Resilient–Ceiling Resilient; FS-CN: Floor Stiff–Ceiling No coupling.

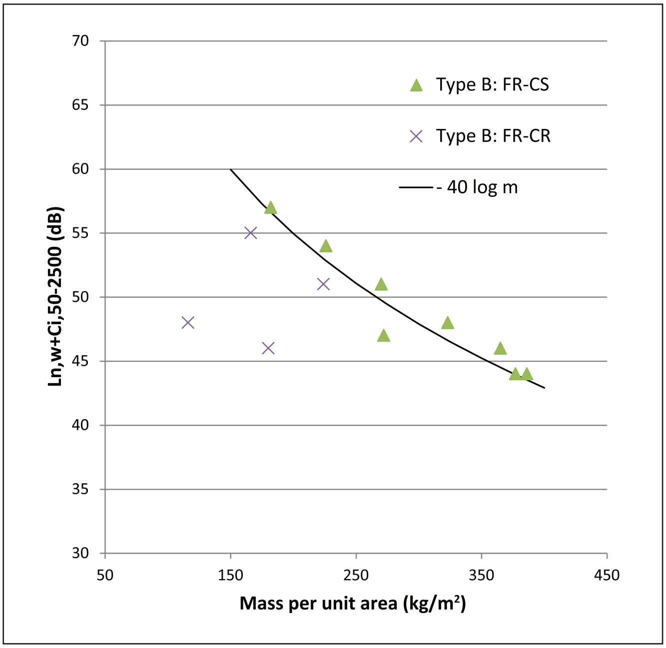


Figure 15. Single number values as a function of mass per unit area, construction type B.

Table 4. Similarities in the frequency domain between different measurement objects.

Frequency domain similarities	Type A	Type B
High or medium	FS-CS, Figure 5 FS-CN, Figure 7 FR-CS, Figure 8	FS-CN, Figure 11
Low	FS-CR, Figure 6(a) FR-CR, Figure 9	FS-CS, Figure 10 FR-CS, Figure 12 FR-CR, Figure 13

FS-CS: Floor Stiff–Ceiling Stiff; FS-CN: Floor Stiff–Ceiling No coupling; FR-CS: Floor Resilient–Ceiling Stiff; FS-CR: Floor Stiff–Ceiling Resilient; FR-CR: Floor Resilient–Ceiling Resilient.

The overview presented in Table 4 shows that all constructions of type A without resilient ceiling present high or medium similarities in the frequency domain, which means that the results are more or less independent of details, products and laboratory conditions. But the comparison shows that the resilient ceiling system itself or in combination with the joist construction and assembly gives a high spread of the impact sound insulation properties in the frequency domain.

Looking into single number quantities, results given in Figure 14 show a high correlation between the $L_{n,w}+C_{I,50\text{-}2500}$ value and the mpua (–30 log mpua) of FS-CR solutions except in the low mpua region. An explanation may be similar (or equal) properties of the resilient profiles used in the Nordic countries. For other floor assemblies, it is not possible to establish a reliable correlation between the $L_{n,w}+C_{I,50\text{-}2500}$ value and the mpua from the collected data.

The compilation also shows that all constructions of type B show poor similarities in the frequency domain, except the solution with a separate ceiling (uncoupled floor and ceiling).

The comparison shows that all types of connections between the joist construction and floor or ceiling elements have an important influence and give a high spread of the impact sound insulation properties in the frequency domain. Considering single number quantities, results given in Figure 15 show a high correlation between the $L_{n,w}+C_{I,50\text{-}2500}$ value and the mpua (–40 log mpua) of FR-CS solutions. This means that the resilient layer at the top floor used in the different countries may have similar properties with respect to dynamic stiffness. Regarding the FR-CR solutions, results given in Figure 15 show a poor correlation between the $L_{n,w}+C_{I,50\text{-}2500}$ value and the mpua (–40 log mpua). The difference in performance between the various type B FR-CR solutions (more than 10 dB) is most probably related to the resilient support used to mount the ceiling.

Conclusion

This article presents the results of numerous well-controlled sound insulation measurements of wooden joist constructions conducted in the laboratory. Comparison of results with different solutions, different products and from different laboratories is of course challenging. But the grouping of constructions has been a very helpful tool to compare and analyse the results.

Considering the total collection of wooden joist construction data (i.e. construction group A), $L_{n,w}+C_{I,50\text{-}2500}$ results from 74 to 49 dB from objects with mpua from approximately 40 to 100 kg/m^2 are found. Similarly, the total collection of data from hybrid wooden joist constructions with gravel or concrete (i.e. construction group B) shows $L_{n,w}+C_{I,50\text{-}2500}$ results from 57 to 44 dB from objects with mpua from approximately 80 to 380 kg/m^2. It means that it is possible to choose solutions within a wide range of impact sound insulation properties and weight of the floor construction.

In the frequency domain, results regarding construction type A show high or medium similarities except objects with resilient ceiling. The comparison shows that the resilient ceiling system itself or in combination with the joist construction and assembly gives a high spreading of the impact sound insulation properties in the frequency domain.

The compilation also shows that all constructions of type B show poor similarities in the frequency domain, except the solution with a separate decoupled ceiling. The comparison shows that all types of connections between the joist construction and floor or ceiling elements have an important influence of the impact sound insulation properties in the frequency domain.

With respect to single number quantities, the picture is a bit different. Regarding construction type A objects, results show a high correlation between the $L_{n,w}+C_{I,50\text{-}2500}$ value and the mpua (–30 log mpua) of FS-CR solutions except in the low mpua region.

Regarding construction type B objects, results display a high correlation between the single number quantity and the mpua (–40 log mpua) of FR-CS solutions. For all other floor assemblies, it is not possible to establish a reliable correlation between the $L_{n,w}+C_{I,50\text{-}2500}$ value and the mpua from the collected data.

The collection of data and result analysis highlight some basic phenomena. For instance, how structural differences related to the grouping of the constructions change the frequency distribution of the impact sound level and the single number quantities. Another significant result is the influence of the mpua of the floors. The mounting of the ceiling also plays an important role in the floor performance. Within the STB project work, these data and results will give us the possibility to optimize existing solutions or develop new floor construction with respect to the impact sound insulation properties itself, geometrical or mass per unit load limitations and other physical issues. Results from this work will also be used for verification of the ongoing research on prediction tools.

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