Timber construction in NZ utilising effective sound insulation

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Introduction

In NZ today there is increased awareness of

- the advantages of using hard floor surfaces such as tile, parquet or timber strip flooring
- The implication of higher density living in apartments adjacent to the CBD
- the power output of the modern stereo system and the prevalence of bass notes in a majority of modern pop music
- increased external noise levels from traffic, both land and airborne, construction work and farm machinery .

There is also a growing perception that some houses/homes are being built in a manner that reduces unwanted sound and demand for this enhanced construction is increasing. Timber framed multi-residential buildings have enabled speeds of erection and a sustainability of materials that are desirable in this energy conscious age and there are some examples of existing buildings that demonstrate how improved insulation is achieved. However research must continue in order to identify how to provide even better performance.

The problem is not just sound levels associated with the spoken word. Below this speech frequency range (especially less than 125 Hz) the low frequencies generated by heavy stereo bass notes are particularly troublesome for our present style of lightweight structure. Other difficulties are caused by impacts (even light footfalls) generating low frequencies transmitted both horizontally and vertically from one apartment to another.
These regions of any noise spectrum are not covered by the US single number system (STC and IIC) currently specified in the NZ and Australian codes.

Proposed upgrading of Codes

Alterations and possible upgrading is being discussed because:

1. The situation addressed by our current NZ code is limited to a minority of home owners who share a partition in common with another dwelling.
2. Performance against non-speech like noises are not rated by the STC. i.e. unwanted fresh and waste water noises, air-conditioning and external motorway noises will not be adequately controlled by specification of a single STC rating.
3. Complaints indicate that a STC limit of 55dB, is not sufficient for certain groups.
4. The intrusion perceived from footfall and other low frequency impact is not clearly recreated by the test impacts generated by the standard tapping machine and the IIC figure of 55dB is often perceived as inadequate.
5. Only component performance is rated and not the influence of the context i.e. the size of the partition.

Current industry efforts to comply with the NZBC requirements [1] (i.e. STC and IIC of 55dB with a tolerance of 5dB for field measurements on intertenancy walls or floors) have given variable results.
During some recent testing [2] in Christchurch, Wellington and Auckland, 23 building elements were measured. 27% of the walls failed the airborne test and 25% of the floors failed the airborne and the impact tests. The failures were from unanticipated flanking paths, incorrect resilient rail and poor workmanship. It is interesting to note that failures also occurred where the building elements were of concrete or masonry.

More demanding controls for NZ are being investigated and steps taken to obviate the criticism of the STC spectrum limitations. A new standard has been suggested to promote enhanced acoustic quality of dwellings. This is following tentatively a European approach that includes the widening of the sound spectrum assessed. This still might be several years away but is a way to meet the current criticisms. It will not be mandatory (unless it is adopted by a TA) but will be available as a guide when insulation greater than the NZBC minimum is desired.
The Australians have also recognised inadequacy in their existing code.[3] Proposed draft revisions show STC lifted to 55dB, clarification of field tests versus laboratory tests and an upgrading of the IIC requirement. The current Australian document includes quote, “Separating walls must.............and together with a satisfactory level of insulation against impact sound”. This style of clause has proven unworkable in practice.

The UK, BRE is currently testing a 6 storey timber test building in their Cardington facility (recently visited by President Bryan Walford). Testing includes performance for:

- differential movement tolerances
- fire
- disproportional collapse
- and **acoustics**

Several floating floor designs are used and most met the target values of 55dB (minimum airborne insulation value) and 58dB (maximum impact sound pressure level). Details of construction assemblages are given in reference 4.

The European approach (unconstrained by our earthquake design demands) is interesting and shows how much the same problems are affecting those communities. Because of the high cost of energy in Europe there is interest in using plantation grown timber rather than concrete and steel. This has meant a growth in timber construction and research papers on the acoustic implications are appearing especially from the Scandinavian and northern European research bodies.
Recent publications have given information about a Nordic Timber Project [5] where Denmark, Finland, Norway and Sweden, have combined to build and study timber framed apartment blocks. A brief description of the projects Orgelbanken (Sweden), Puukotka (Finland) and Walludden (Sweden) is given in the following pages.

The Nordic Projects [5]

These reports all use ISO measures expressed in single figure values
airborne sound;

R_w - weighted, normalised sound insulation, measured in the laboratory

R'_w - as above but field measured

Impact sound;

L_{nw} - weighted normalised sound pressure level, measured in the laboratory

L'_{nw} - as above but field measured

The airborne sound insulation is the difference between the source noise and the received noise, therefore the greater the numerical value the better the insulation.
The impact sound is the noise received from a tapping machine therefore the greater the numerical value the worse the insulation.
These can be related approximately to our NZ ratings as follows; $STC \approx Rw$
$IIC \approx 110 - Lnw$

Architectural layouts

These Nordic projects have complimented our local publications by providing full case study information.

Orgelbanken (Sweden)

2500m2, 4 stories with attic storage. [5]
36 apartments, in 1 block , 3 separate access stairs
Construction commenced 95
Floor plan

Walls	The majority of internal and external walls are loadbearing Internal studs, 45x120 @ 600cc, facade studs 45x145 @ 600cc All timber used with max 18%mc at delivery.
Floors	Joists 95x400 LVL, at 600cc, span 5m All floors constructed as continuous structural diaphragms.
Roof	Timber trusses spanning outer wall to outer wall.
Lateral strength	Bracing panels to internal and external walls using gypsum board (to 3.5kN) and plywood (greater than 3.5kN)
Foundations	Concrete strip
Fire	All passive resistance to local standard BBR94 (performance based) Resistance specified on dividing elements (load bearing or no). Spread of fire through cavities inside the building and from one fire cell to another stopped with mineral wool (28kg/m3) Balconies, galleries and stairways all rated as escape routes.
Sound	Double stud party walls, floating floors over the structural OSB sheets Balconies structurally separated

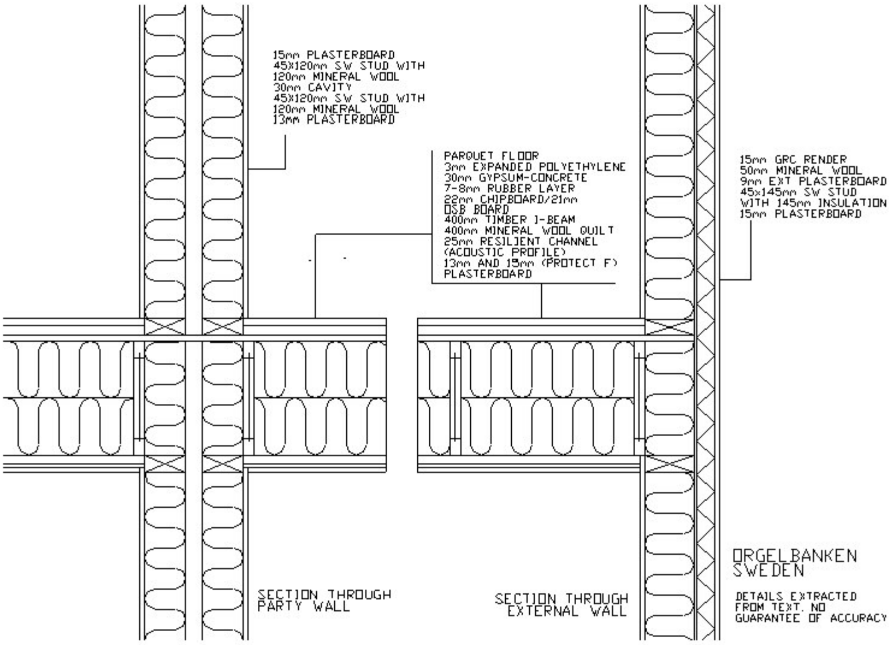
		airborne	impact
Floors	BBR 94	≥52dB	<58dB
	ISO + C ψ	≥55dB	<53dB
	field measure	60dB	49dB
Walls	field measure	62dB	

ψ spectrum adaption term extending frequency range assessed

For typical cross sections refer to the following page

Conclusions

1. Rubbermatting and gypsum concrete not cost effective
2. Future projects will avoid attic storage.
3. External rendering with grc, (thin render specification) was a very slow application



Typical Floor / Wall Construction for the Orgelbanken project

Puukotka (Finland)

2,190m2, 33flats, 3 stories. [5]
Construction started May 96
Floor plan - terrace style in 3 blocks

Floors Titanite joists (LVL) spans 3-4500m, 45x195 @ 300-650cc
Floating floor being 600x2400 sheets 22mm thick T &G and glued
Plastic sheet flooring over.

Walls External and party walls are loadbearing and contribute to lateral strength
External wall, 48x172 studs @ 600cc
Party walls, 2 / 61x97 studs @ 400cc lower stories, 600cc upper stories.

Structural diaphragm Described as a continuous stabilising element providing essential lateral stability.

Roof Prefabricated roof trusses with nail plate connections

Fire Sprinklered and with fire alarms. Walls and floors rated B60
Local fire regulations demanded non-combustible materials for load bearing elements of the gallery and access stairs
All load bearing elements of the building frame to be 1hr FRR
The building is sited to allow access by fire engine on all sides.

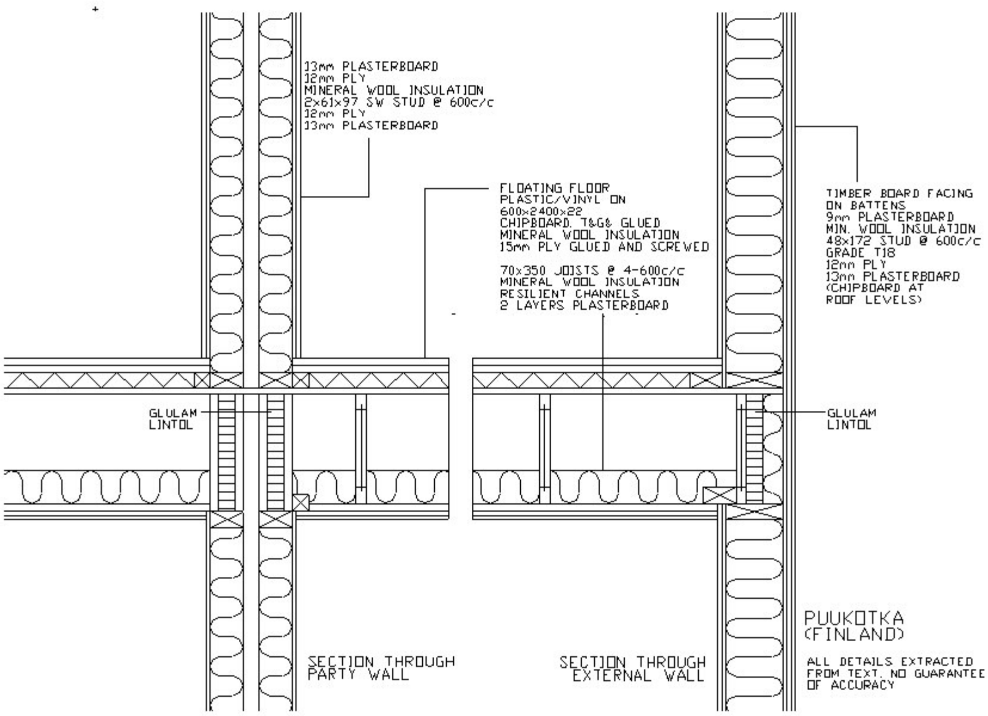
Lift shaft concrete

Foundation concrete slab

Sound-			airborne	impact
	Floors			
		insuln designed	53dB	58dB
		lab tested	61dB	54dB
		field measure	61-65dB	45-54dB
		Fin reguln.	53dB	58dB
	Party walls			
		insuln design	53dB	
		lab tested	-	
		field measure	58dB	
		Fin reguln.	52dB	

Façade 100% timber

For typical cross sections refer to the following page



Typical Floor / Wall Construction for the Puukotka project

Walludden (Sweden)

2,850m2, 36 flats, 4 &5 stories high, 2 separate blocks [5]
Construction commenced in Aug '95

Floor plan:

Foundations Concrete slab.

Access Lifts and entrance stairs, 1 for each block.

Lift Shaft framed in glulam beams 115x225, partly exposed through glass panels.

Balconies Columns 180sq and beams 90x270 &180.

Floors Joists 45x300 LVL @ 600cc with a continuous steel deck over and floating floor above. The steel deck being .45mm sheet folded to a trapezoidal profile, 45mm deep. The cavity between the joists being totally filled with loosefill insulation.
Floating floor being 2 / 13mm plaster board, capped with ragboard and parquet flooring. The ceiling being 2 sheets, 13mm plasterboard fixed on 25mm sound insulating battens at 400cc.

Roof Timber trusses at 1200cc
Suspended ceiling with 2/13mm sheets plaster board on resilient channels. Trusses decked with 22mm T&G boarding with multi layers of roof felt over.

Lateral strength is provided by both internal and external walls. Upper levels - plasterboard only. Lower levels plywood and plaster -board together. Compound posts at the end of walls resisting windload constructed of up to 6 studs.

Walls 45x120 studs@600cc, mineral wool insulation and external rendering onto a 50mm "rendered insulation board" Where timber is used on the facade this fixed onto 45x45 battens @ 600cc and cavity filled with mineral wool insulation. A 3rd inner layer being a 70mm plumbing and wiring duct, 45x70 studs at 300cc filled with mineral wool insulation.
Party walls being double frames using 2 / 45x120studs and plywood sheeting and covered with 2 layers of 15mm plasterboard.

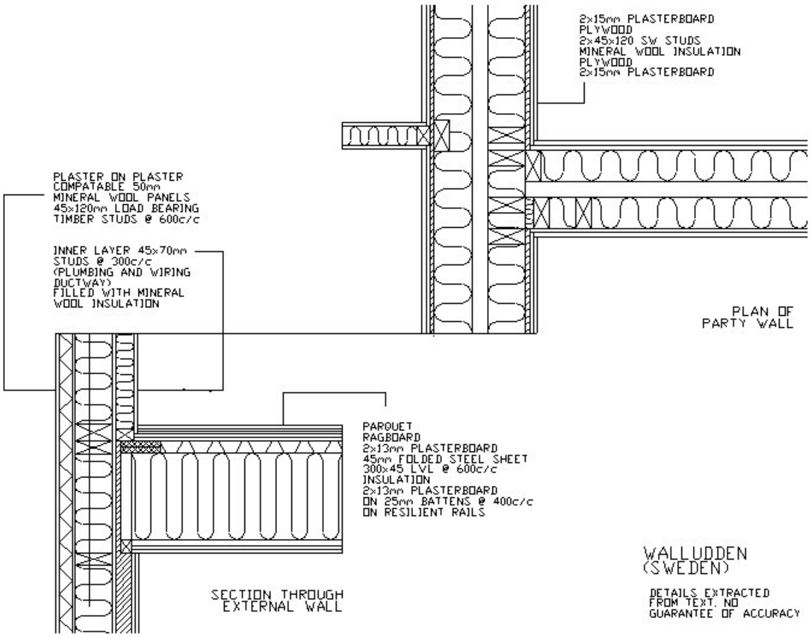
Fire All to local BBR94 standard (function based) and using passive systems.
Vertical and lateral load bearing 60min (90min for 5-8 stories) Floors 60min. Apartment separation (fire cell dividing wall) 60min. Spread of fire and smoke through the cavities prevented by fire stops consisting of solid 45mm timber bridging struts.

Sound

Floors,	airborne	impact
Swedish housing regn.BBR94	>53dB	<58dB
field measured	57dB	50dB

Facade Rendered but part timber

For typical cross sections refer to the following page



Typical Floor / Wall Construction for the Walludden project

The Walludden project demonstrates a common stairway/lift where only vertical (wall) insulation from the neighbouring apartment or noise from the stairway needs special attention. All three project buildings show the desirable arrangement of utility rooms or kitchens placed adjacent to or on top of each other.

These measures are commonly considered good practice in NZ to minimise plumbing costs in any constructions as well as timber frame construction. The projects however further illustrate that where layout plans are carefully thought through the opportunities for achieving acoustically acceptable living conditions are greatly enhanced.

Structural Diaphragms

A floor, when detailed and constructed as a *structural diaphragm* has the capability to spread wind and earthquake lateral loads onto all vertical shear wall elements. As apartment blocks rise to 4-5 stories, as is happening in Scandinavia, bracing demand from lateral loading is high enough to require all available walls to contribute to providing lateral resistance. A continuous *structural diaphragm* achieves this and will spread the load in proportion to the available wall stiffness. The conventional design of such an element assumes the floor sheeting (i.e. the working platform) is the girder web and the floor edge beams are the girder flanges. All sheeting joints are connected by nailing into joists or dwangs or blocking pieces. Cutting the diaphragm sheeting at or adjacent to any party wall can often be managed structurally and is effective in limiting the transfer of noise, especially impact across these walls. This special measure is currently utilised in the 2-3 storey terrace style apartments being built in the moderate wind and earthquake areas of NZ.

The Nordic Timber project buildings (Orgelbanken and Walludden) show European examples of much larger buildings than are being built locally, eg floor plates approx 625m2 (divided into nine apartments). The floor joists run in both directions and apartments need sound control both vertically and horizontally. There is no regular pattern of structure, which would allow the *structural diaphragm* to be cut.
For these projects a **floating floor** is the only available solution. This style of floor will increase floor mass to help resist the airborne sound and will isolate the structure to reduce the penetration of impact sound.

Floating Floors

Can be assembled in various forms, but all concentrate on isolating the upper floor surface from the structural or the working platform.

Orgelbanken (Sweden) is a 53mm build-up of:
8mm of rubber matting, 30mm of gypsum concrete, 3mm expanded polyethylene topped with wooden parquet flooring - surface mass 72 kg/m2
Walludden (Sweden) uses a working platform of a .45mm steel sheet prefolded to a trapezoidal shape 45 mm in depth with a floating build-up of 42mm:
2 layers of 13mm gypsum board, a rag board layer capped with 12mm of wooden parquet - surface mass 30 kg/m2 but 35kg/m2 when including the weight of the steel floor (i.e. the working platform).

Another project (not detailed here) is in Solbakken(Norway) used an 88mm build-up:
25mm of mineral wool, 13mm plasterboard, 22mm chip board, 3mm of expanded polyethylene topped with wooden parquet floor - surface mass 33 kg/m2

All floors use these extra sheets of gypsum and particleboards, loose laid between the wall plates, requiring deeper wall plates and extra construction time. It is noted in some Scandinavian conference papers that builders have objected to the extra time and materials needed to place these sheets however the results speak for themselves:

Orgelbanken,	airborne	60dB	
	Impact	49dB	(IIC61)
Walludden,	airborne	56-58dB	
	Impact	50-52dB	(IIC58)
Solbakken,	airborne	62-61dB	
	impact	46-48dB	(IIC 62)

All of the above IIC figures are well in excess of what is achieved by most local constructions without carpeting.

Balcony and corridor construction

Balconies and access corridors supported directly from load bearing structure or supported on floor joists acting as cantilever beams will allow impact noise from these areas to transfer to any adjacent area either horizontally or vertically. The only solution is for the balcony to have its own separate structure or a floating floor or damping measures on this -often modest- area.

Plumbing and HVAC installation

Reference 6, gives several instances of failures attributed to piping. Installation of HVAC pipes into the resilient layer of a floating floor is one such example. When the diameter of the pipe is similar in thickness to the resilient layer the surface plates of the floor have contact with the bearing structure increasing the impact transmissions. The Walludden project shows an extra internal frame around all external walls providing a 70mm void for all wiring, plumbing and other piping. This would not be necessary in the more lightly serviced NZ apartment but it is an example of the detail considered necessary in that particular project.

Floor Joist stiffness

The NZ structures code requires the avoidance of joist systems having a resonance frequency of < 8Hz because of the risk of subjective effects. It is pointed out that frequencies of approx 3Hz can lead to resonance with walking traffic and 5-8Hz coincides with potential resonance of the human organs making people feel uncomfortable or even generating nausea. Ideally floors should be planned to achieve a frequency of >12Hz but there is on record an example of a washing machine causing noise levels from 47-52dB measured in an apartment below a timber floor with a span of 5m and a fundamental frequency of 18Hz.[6]

There are measures to improve vibration performance including increasing joist size, increasing joist elastic modulus and spacing and supporting the floor on all four sides.

A floor designed with a natural frequency significantly lower would be acceptable in principal but would need strong damping to avoid unpleasant subjective reactions.

Joist stiffness must also be considered in relation to wall stiffness - discussed below

Junction design and Boundary Damping

To avoid the transfer of panel vibrations to a contiguous support, the panels (either floor or wall) must be appropriately connected to the supporting structure. The greater the structural fixity the greater will be the vibration transfer. This discourages any type of structurally continuous floor planned or designed to reduce structural depth or deflection.

Ideally all floor joists should be run parallel to the party wall but this must be balanced against the desirability of improving the 2 way floor action mentioned earlier. If the floor joists must bear on the party wall the use of flexible hangars has shown to be beneficial [4]

The floating floor, used primarily to reduce impact noise is appropriate because of its disconnection from the working platform and the lack of bonding in its assemblage. This promotes damping and reduces vibration transfer. Any technique that provides damping at the periphery of a floor or a wall panel can be expected to reduce the impact noise transfer. Methods to test and develop theories on how this is done are still being developed [9]

This discussion presented so far constitutes a strong discouragement for the development of timber buildings structured with any continuous (MR) frame. To achieve the desired control of unwanted sound we suggest the focus must be on wall stiffened construction.

Efforts to provide increased damping will mean changes in the currently accepted way of framing a timber building. Presentation of this information -especially to the builder- will require more than the brief sketches often currently supplied by the architect and structural engineer to supplement the details of NZS 3604. Drawings in 3D (CAD generated) will be necessary to clearly show placement of the different fixings and materials used.[5]

Subjective Evaluations

People display a range of sensitivities in their responses to any stimulus and consequently they will react in different ways. So there is always a range of opinions as to what is acceptable or what is not. The assessment of what is unwanted sound is no exception.

The first step in the Nordic Project was to formulate functional requirements based on how the occupants rate the effectiveness of any sound insulation. The next step was to devise methods for evaluating proven structures so that the results

would agree with the perception of the occupants. Finally an interview survey was conducted among the residents to determine how the results of the assessment measured up to their original perceptions.
The method of evaluation used involved widening the spectrum of measurement and using the Bodlund method[5] of weighting the results into a single figure rating. This method (as other more recent techniques) takes into account low frequency sound down to 50Hz. The objective was that 90% of the occupants should rate the impact sound insulation as satisfactory or better.
Stairwells (or galleries) and lift shafts (see above) were also the subject of special attention as the impact sound pressure generated by people walking up and down stairs can be very high and usually higher than the corresponding sound pressure from people walking on a floor. Every effort was made to either float or isolate these areas from the main building structure. In the Puukotka project, access galleries and stairs were constructed in reinforced concrete to ensure isolation from the timber-framed apartments.

It is desirable that local test developments should include subjective testing and because of the number of potential influences involved it is essential to have well trained assessors Acceptability of unwanted noise can depend on [7]:

1 what the individual is doing.
2 the orientation of the person whether they are lying down sitting or standing up
3 there is less tolerance of continuous than a transient loading.
4 there is more tolerance of the odd impact noise than that generated by a person walking
5 the time of day
6 personality of the individual

A local testing programme

We are proposing to investigate how to attain effective sound insulation and focus on the problem of impact sound transfer. This research programme is being planned (Forest Research in conjunction with University of Auckland) to investigate acoustic insulation results for a number of assemblages made up from NZ sourced materials.
To do this we plan to assemble sample floors and walls within the context of an existing building.[8]

Major variables investigated will be:
- mass of floor layers and ceiling layers
- use of resilient channels and sound absorbent materials

Other variables will include:
- overall depth of floor
- the bonding of floor sheets and the fixing of resilient channels
- Joist type, solid wood, wood truss, I joists, LVL.
- Sound absorbing materials, glass fibres, rock fibres, cellulose fibres (sprayed or loose)

The programme of measurements will collect data on
- impact sound transmission vertically and diagonally
- airborne sound insulation horizontally, vertically and diagonally
- flanking transmission
- repeatability and reproducibility
- subjective evaluations of the differently performing assemblies

Processing of data will include regression analysis intended to produce a useful empirical model.

Conclusion

We have addressed the fact that current NZ construction is not achieving a level of sound control (especially impact) that satisfies a majority of occupants. In this we are not unique.
Other timber oriented regions (North America and Scandinavia) have been working for several years to find solutions and the results from some of their trial buildings we have included here. These results could be showing NZ a direction to follow.
Unfortunately we cannot directly transpose these results to our own situation and only testing with NZ materials fixed in a manner to suit our own style of framing will ensure we have long term answers.

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